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PRELIMINARY REPORT OF THE SPECIAL COMMISSION TO INVESTIGATE THE WATER SUPPLY OF THE CITY OF PHILADELPHIA.

Philadelphia, October 14, 1882.

To the Select and Common Councils
of the City of Philadelphia.

GENTLEMEN:—The undersigned, having been appointed by his Honor the Mayor, in conformity with the ordinance approved June 7, 1882, authorizing him to appoint a Board of Experts, to "report to Councils the methods pursued in the Water Department, together with their recommendations of what should be done for the present and future supply of the City, with such itemized estimates as will enable the cost to be determined," have the honor to state, that they met September 19th, and have been continuously engaged in examining and studying the subject; that the problem presented to them is of so large, complex, and important a character, that they are unable at this time to report upon the future supply; but that their examinations thus far have revealed a condition of affairs in regard to the present supply of water to the City, which does not justify delay upon their part in presenting this partial report for the consideration of your honorable bodies.

They find that in supplying the lower levels of the City the existing

machinery has been worked to its utmost capacity; that at the two largest steam works there is no spare machinery, and in two others the whole supply depends upon one engine in each. They also find that at the rate of annual increase in largest consumption of the past year (which is about eleven (11) million gallons daily) there will not be enough pumping power to sufficiently supply, during the driest seasons of next year, an area which contains two-thirds of the population, while in 1884 there will be a short supply throughout almost the whole City.

Nor can an abundant flow of water in the Schuylkill be relied on to avert this catastrophe next year; for not only is such a flow, when it is most needed, unlikely, but the amount which could then be furnished by the Fairmount wheels is to the lower levels only, and would be entirely inadequate to supply the deficiency.

Indeed, the time has come, when it is necessary to face the fact that during periods of least flow of water, which are also those of greatest consumption, the water power at Fairmount is practically unavailable.

It is also to be noted that machinery is not always in good working order. Pumping engines and boilers must be stopped for repairs, and accidents occur to engines and pumps, and from breakage of mains. For these reasons it is customary in other cities, where there is abundant reservoir capacity, to add at least one-third to the pumping power which is ordinarily needed at periods of the greatest consumption.

Your Board regard the following named machinery and appliances as imperatively needed for the supply of water to the City in the summer of 1883. In their opinion, none of them can be dispensed with, except at the risk of serious results, in the localities supplied by the specified pumping stations.

I. FOR SCHUYLKILL WORKS.

Two (2) Fifteen million gallon engines to pump, one against 150 feet, one against a higher head	$96,000
Two (2) ranges of boilers and connections	60,000
Two (2) forcing mains	30,000
Completing 48-inch main partly laid	14,000
Boiler and engine house	40,000
Foundation for same	10,000
Total	$250,000

II. FOR ROXBOROUGH WORKS.

One (1) Seven and a half million gallon engine to pump against 360 feet head, with forcing main in house....	$50,000
Removing old and substituting two boilers and connections..	7,000
New inlet, screen, and dredging.....	3,000
Total	$60,000
Distributing main to supply Germantown, from Mt. Airy Reservoir to Manheim, on Green.....	$70,000

III. FOR FRANKFORD WORKS.

One (1) Ten million gallon engine and connections, to pump against 200 feet.....	$45,000

As to the character of the machinery to be obtained the estimates given for the engines refer to the "Worthington Compound Duplex," which the Board consider to be reliable, comparatively free from liability to serious accident, not expensive in first cost and maintenance, and fairly economical in fuel. To supply an emergency like the present, where time for construction and erection is extremely short, they know of no other type which, on the whole, presents so many advantages.

In regard to boilers, they recommend and have estimated for the cylindrical, tubular at Roxborough Works, like those just bought; and for Schuylkill Works marine tubular boilers, which, although of greater first cost, present certain important advantages in preparing for an emergency, and are at least equal to the others in the economy of fuel and repairs.

Your Board have reason to believe that if the above recommendations are adopted, and contracts for the machinery are entered into before December 1st next, that two of the engines can be used by June 1, 1883, and the other two by August 1st of the same year, although the time is short, both for consideration of the subject, and the execution of the work.

Your Board are satisfied of the great importance of an early completion of the East Park Reservoir, entire, with its connecting, forcing, and distributing mains; and of building a reservoir at Cambria and Thirtieth streets; and of adding to that at Mount Airy. For both of the latter, land should be acquired at once. All of them are needed now, and will ultimately form proper centres of distribution, whatever may be the permanent source of supply for the City.

The importance of reservoirs is due not only to the necessity for subsidence, but also to guard against the results of serious accidents, such as the experience of this and other cities shows are liable to occur.

The appropriations for these reservoirs are next in importance to those for the machinery, for which estimates have been given.

Expenditures under such appropriations would extend over a period of at least three years, 1883 to 1885. The following estimates of probable cost are believed to be sufficiently accurate to be a basis for appropriation:

I. EAST PARK RESERVOIR AND CONNECTIONS.

Completing two basins	$400,000
" the third basin	300,000
Forcing mains	126,000
Distributing mains	371,200
Total	$1,197,200

II. CAMBRIA RESERVOIR AND CONNECTIONS.

Land, say	$100,000
150,000,000 gallon reservoir	375,000
Forcing and connecting mains	240,000
Distributing main (one)	105,000
Total	$820,000

III. MT. AIRY RESERVOIR.

Land, say	$25,000
75,000,000 gallon reservoir	225,000
Total	$250,000

Of these amounts there should be expended—

In 1883, at East Park, finishing small basin and work on others	$372,500
Cambria, land and work	200,000
Mount Airy, land and work	75,000
Total, first year	$647,500

In 1884, at East Park, finishing second basin and work on other, and main	$340,000
Cambria, work on basin and main	325,000
Mount Airy, work on basin	100,000
Total, second year	$765,000
In 1885, at East Park, finishing basins and mains	$484,700
Cambria, " " " "	295,000
Mount Airy, finishing basin	75,000
Total, third year	$854,700

In considering the question of "present supply," it should be borne in mind that at least five years must elapse before a gravity system, such as contemplated by the Perkiomen or Delaware projects, could be accomplished. At least one year would be spent in making surveys, plans, and detailed specifications. Their discussion and adoption would consume another year, at least; and the construction of the works would take three or four years more, supposing that the funds for so large an undertaking could be provided in that time.

This is a sufficient reason for providing for an adequate water supply by steam pumping machinery and by storage in reservoirs, up to 1888. Long before that time, if the present rate of increase of demand prevails, the consumption of water will become so large as to demand a still further increase than has been recommended in this report, both in pumping power and in distributing facilities, which are now in many localities far below the demand. A consideration of these points may, however, be safely left for the final report of this Board.

Meanwhile your attention is respectfully called to the fact that complete surveys must be made, and reliable data obtained, of the localities from which and through which a pure water supply can be drawn, in order to form a correct judgment as to their availability. As it is essential that this information be obtained, an appropriation for such surveys of not less than fifteen thousand dollars ($15,000) is suggested.

With regard to the management of the pumping stations, your Board would call attention to the system which is now, and has been since the earlier days of the Department, the prevailing one, as being radically wrong.

At each of these stations there are now two engineers of equal authority, who are on duty alternately during the day and the night.

Thus there can be no definite responsibility or uniformity of management.

The Board recommend that this organization be so modified as to place one superior engineer in charge of each station. In the two larger stations—Schuylkill and Belmont—he should not be required to take a watch, but have two competent assistants. At the other works he might take a watch and have one assistant. He should, in all cases, be responsible only to the head of the Department, and should maintain discipline, receipt for supplies, provide spares, supervise repairs or any additional construction going on, and direct the proper use of the machinery. Such men should be paid good salaries, commensurate with their qualifications and the responsibility placed upon them.

The Board also consider that the salaries now paid to engineers, corresponding to those of the assistants under the proposed plan, being less than those of good mechanics, in proportion to the time they are on duty, and far below those paid in other cities for similar work, are insufficient to command and keep the best men. They believe that the saving in fuel alone which would result from these changes would more than pay the extra amount required for wages, and that greater security would be obtained.

They also suggest that the several pumping stations and reservoirs should be connected together and with the Purveyor's and central office by telephonic communication, the immense value of which at all times, and especially in case of accidents, is obvious.

The Board have been deeply impressed with the vital necessity of keeping out of the inlets to different pumping wells a large and constantly increasing amount of offensive sewage. They believe that this great evil, so far as it proceeds from the sewer that empties into the Schuylkill river at the east end of Girard avenue bridge, can be abated at an early day, and at a cost small in comparison with the importance of the object.

This, nowever, belongs to the Survey Department of the City, which has also under consideration methods for keeping the sewage of Manayunk and the points below it out of the river above Fairmount dam.

This is a necessity which cannot be too soon provided for, considering the importance of restoring the water supply to its original purity, and, at the same time, of protecting the great industries of that section.

Appended to this report, the Board submit a table showing the pumping capacity and consumption for a series of years; also a table showing the organization and wages paid in different cities.

Respectfully submitted.

E. S. CHESBROUGH,
J. VAUGHAN MERRICK,
FRED. GRAFF.

WM. H. MCFADDEN, *Chief Eng. Water Dept.*

Table showing the available capacity of Works of Philadelphia Water Department, in millions of gallons per day, from 1872 to 1883, at time of maximum demand, the reserve engines at time of accident or break down of machinery, and the probable deficit for 1883.

Year.	Steam power. M. g. p. d.	Water power. M. g. p. d.	Total. M. g. p. d.	Demand. M. g. p. d.	Reserve engines unavailable.*	Deficit.	
						If no accident.	If an accident to the largest engine.
1872	41	15	56	45	10	.....	.....
1873	43	15	58	49	10	.....	.....
1874	43	15	58	50	10	.....	.....
1875	43	15	58	52	10	.....	.....
1876	47	15	62	62	10	.....	.....
1877	47	22	69	57	25	.....	.....
1878	60½	20	80½	64	14	.....	.....
1879	59½	7½	67	65	14	.....	6
1880	59½	7½	67	67	14	.....	6
1881	74	5	79	75	9	.....	11
1882	74	13½	87½	86	9	.....	11
1883	74	5	79	100	9	21	32

NOTE.—If the large engine at Frankford breaks down, there will be a short supply at Frankford; and if the larger engine at Roxborough or its boilers break down, a failure at Germantown will be the result.

* Unavailable on account of want of boilers or pumping main.

Cities	St. Louis.		Brooklyn.		Cincinnati.		Philadelphia.	
Pumping stations	.....	.....	Ridgewood		Main Works.		Spring Garden.	
Lift in feet	$\frac{230+40}{2}$	135	171		171		134	
Max. mill's gall's into reservoir	35+2	70	37		37		45	
Max. work mill's gall's 100 feet high	.....	94·50	63·27		63·27		60·30	
	No.	Pay per day.	No.	Pay per day.	No.	Pay per day.	No.	Pay per day.
Engineers in charge	1	$6.95	1	$6.85.	1	$5.00	2	$2.46.
Assistant engineers	9	4.50 3.33 4.16 3.17 3.80 3.00 3.50 2.80 2.60	8	3.61 to 3.28	5	3.50	.....	None
Oilers	6	2.00	5	2.05	10	2.00	8	1.90
Firemen	24	2.00 1.83	16	1.97	13	2.00	10	1.90
Coal passers	20	1.66	6	1.81	6	2.00	4	1.90
Gaugemen	.....	None.	.....	None	.....	None	2	1.90
Laborers	.....	Not specified	6	1.75	.....	Not specified	1	1.75
Coal weighers	.....	.....	.....	.....	3	3.00 2.00	.....	.....
Clerks	.....	.....	.....	.....	1	3.00	1	1.90
Flue cleaners	.....	.....	.....	.....	1	1.75	.....	.....
Total wages per diem	60	$128.97	42	$97.54	40	$92.25	28	$54.17
Cost of labor per million gallons lifted 100 ft. high	.....	$1.36	.....	$1.54	.....	$1.45	.....	.90c.

NOTE.—At St. Louis the water is first pumped from the Mississippi river, 40 feet, into settling basins; from thence into the distributing reservoir, 230 feet high; the average lift being 135 feet for double the consumption of 35,000,000 gallons, or 70,000,000 gallons 135 feet high = 94½ million gallons 100 feet high.

Cities	Louisville		Chicago.		Philadelphia.	
Pumping stations			West Side		Belmont.	
Lift in feet	175 ft.		100 ft.		212 ft.	
Maximum millions gallons into reservoir	11 mill's		30 mill's		18 mill's	
Maximum work millions gallons 100 feet high	19·25		30·00		38·16	
	No.	Pay per day.	No.	Pay per day.	No.	Pay per day.
Engineers in charge	1	$5.00	1	$6.85	2	$2.46
Assistant engineers	3	4.52 4.31 1.61	3	4.39	.....	None
Oilers	2	2.18	4	2.13	4	1.90
Firemen	2	2.18	6	2.23 2.13	10	1.90
Coal passers	2	2.18	3	1.97	4	1.90
Gaugemen	.....	.....	.....	.....	2	1.90
Laborers	.....	.....	.....	.....	1	1.75
Coal weighers	1	2.18	1	2.13	.....	None
Clerks	.....	.....	.....	.....	1	1.90
Flue cleaners	.....	.....	2	2.13 1.97	.....	.....
Total wages per diem	11	$30.70	20	$53.76	24	$46.57
Cost of labor per million gallons lifted 100 feet high	.....	$1.59	.....	$1.79	.....	$1.22

ON THE APPLICATION OF THE PRINCIPLE OF VIRTUAL VELOCITIES TO THE DETERMINATION OF THE DEFLECTION AND STRESSES OF FRAMES.

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(Concluded from page 204.)

We may show here, however, how the continuous girder may be treated in a rather different manner from that explained in the previous pages. We will confine ourselves to the case represented in figure 11, the web system being simple, in which case the structure is statically determined as regards the inner forces. As regards the outer forces it is undetermined, there being n—1 equations failing. But it is clear that if we omit the chord pieces over each point of support, as in the figure, we reduce the structure to n simple girders, and it becomes in every way statically determined. Our problem is thus reduced to finding the $n - 1$ stresses S', S'', S''', etc., in the chord pieces over the piers, and this problem may be solved by a method exactly analogous to that pursued in treating trusses with superfluous bars, for in this case the chord pieces referred to are superfluous, and by removing them the system becomes statically determined. The only difference in the two cases is, that before the system was already statically determined regarding the *outer* forces, and was made so regarding the *inner* forces by removing the superfluous bars; while here, the system is already statically determined regarding the *inner* forces, and is made so regarding the *outer* forces by removing those bars. The method of treatment is in both cases precisely the same. We have, if we apply at A and B, acting towards each other, and hence representing tension, forces equal to unity, for the shortening of AB.*

$$\Delta\lambda_2 = \Sigma\, u''\, \Delta l,$$

u_1'', u_2'', u_3'', etc., being the stresses produced in the bars of the (statically determined) system by the forces unity in A and B, and Δl_1, Δl_2, Δl_3, etc., being the changes in length of those bars. If, as before, the stresses produced in the necessary bars by the given applied loads be

* The upper chord joints on each side of R_3 should be lettered A and B.

called Y_1, Y_2, Y_3, etc. (which may be found by statics alone), then the real stresses S_1, S_2, S_3, etc., in those bars are given by the following equations, as before:

$$\left.\begin{aligned} S_1 &= Y_1 + u_1'S' + u_1''S'' +, \text{ etc.}, \\ S_2 &= Y_2 + u_2'S' + u_2''S'' +, \text{ etc.}, \end{aligned}\right\} \quad (39)$$

etc., etc.

Remembering now that a force in $A\ B$ affects only the bars in the two adjacent spans, and that therefore u' exists only for the bars in the first and second spans, u'' only for those in the second and third, and so on, we have

$$\left.\begin{aligned} -K'S' &= \Sigma^{1,2}\, u'\, K\, S \\ -K''S'' &= \Sigma^{2,3}\, u''\, K\, S \\ -K'''S''' &= \Sigma^{3,4}\, u'''\, K\, S \end{aligned}\right\} \quad (41a)$$

the numbers above the sign of summation denoting the spans over which the summation is to extend. If we substitute now in these equations the values of S, etc., from equations (39), we have the following, due regard being paid to the above remark regarding the spans considered:

$$\left.\begin{aligned} o &= K'S' + \Sigma^{1,2}\, u'\, K\, Y + S'\, \Sigma^{1,2}\, u'^2\, K + S''\, \Sigma^{2}\, u'\, u''\, K \\ o &= K''S'' + \Sigma^{2,3}\, u''\, K\, Y + S'\, \Sigma^{2}\, u''\, u'\, K + S''\, \Sigma^{2,3}\, u''^2\, K + \\ &\quad S'''\, \Sigma^{3}\, u''\, u'''\, K \\ o &= K'''S''' + \Sigma^{3,4}\, u'''\, K\, Y + S''\, \Sigma^{3}\, u'''\, u''\, K + S'''\, \Sigma^{3,4} \\ &\quad u'''^2\, K + S^{iv}\, \Sigma^{4}\, u'''\, u^{iv}\, K \end{aligned}\right\} \quad (44)$$

etc.

These equations are equal in number to the superfluous bars, there being one for each pier. From them we can obtain by elimination the values of the unknown quantities S', S'', S''', etc., and the problem is solved, the true stresses S_1, S_2, etc., being found by equations (39). In case the arrangement of the bars is not as represented in the figure, it is easy to see which bar shall be considered superfluous, and further explanation is scarcely necessary. We will only now show how the above equations, which are very much more general than those derived from the Theorem of Three Movements, reduce to the latter in a particular case. Suppose the girder to have a constant moment of inertia, and let us neglect the influence of the web members. Let each chord have a section F. Let the second and third spans be loaded uniformly with q_2 and q_3 pounds per running foot. Let distances, in either span, from the second pier, be called x. Then the number of joints in each chord is to be considered infinitely large, and the length of each chord

piece is dx. Hence $K = \frac{dx}{EF}$. The values of the different quantities in the second equation (44) will be found to be as follows:

2d Span.
Upper chord.

$$\begin{cases} Y = -\frac{q_2 x (L_2 - x)}{2h} \\ u' = +\frac{1 \cdot h}{L_2} \cdot \frac{x}{h} = +\frac{x}{L_2} \\ u'' = +\frac{1 \cdot h}{L_2} \cdot \frac{L_2 - x}{h} = +\frac{L_2 - x}{L_2}. \end{cases}$$

Lower chord.

$$\begin{cases} Y = +\frac{q_2 x (L_2 - x)}{2h} \\ u' = -\frac{x}{L_2} \\ u'' = -\frac{L_2 - x}{L_2} \end{cases}$$

3d Span.
Upper chord.

$$\begin{cases} Y = -\frac{q_3 x (L_3 - x)}{2h} \\ u'' = +\frac{1 \cdot h}{L_3} \cdot \frac{L_3 - x}{h} = +\frac{L_3 - x}{L_3} \\ u''' = +\frac{1 \cdot h}{L_3} \cdot \frac{x}{h} = +\frac{x}{L_3} \end{cases}$$

Lower chord.

$$\begin{cases} Y = +\frac{q_3 x (L_3 - x)}{2h} \\ u'' = -\frac{L_3 - x}{L_3} \\ u''' = -\frac{x}{L_3} \end{cases}$$

The sign of summation in equation (44) becomes a sign of integration, and the values of the different terms are as follows:

$$K'' S'' = S'' \frac{dx}{EF} \qquad (45)$$

$$\left.\begin{aligned}\Sigma^{2,3}\, u''\, K\, Y = &-\int_0^{L_2} 2\,.\left(\frac{L_2-x}{L_2}\right)\left(\frac{dx}{EF}\right)\left[\frac{q_2\, x\,(L_2-x)}{2h}\right]\\ &-\int_0^{L_3} 2\,.\left(\frac{L_3-x}{L_3}\right)\left(\frac{dx}{EF}\right)\left[\frac{q_3\, x\,(L_3-x)}{2h}\right] = -\frac{1}{EFh}\\ &\left\{\frac{q_2}{L_2}\int_0^{L_2}(L_2-x)^2\, x\, dx + \frac{q_3}{L_3}\int_0^{L_3}(L_3-x)^2\, x\, dx\right\}\\ &= -\frac{q_2\, L_2^3 + q_3\, L_3^3}{12\,.\,EF\,h}\end{aligned}\right\} \quad (46)$$

$$\left.\begin{aligned}S'\,\Sigma^2\, u''\, u'\, K = +\, S'\,&\left\{\int_0^{L_2} 2\,.\,\frac{x\,(L_2-x)}{L_2^2}\cdot\frac{dx}{EF}\right\} =\\ &+\frac{S'\,L_2}{3EF}\end{aligned}\right\} \quad (47)$$

$$\left.\begin{aligned}S''\,\Sigma^{2,3}\, u'^2\, K = +\, S''\,&\left\{\int_0^{L_2} 2\,.\,\frac{(L_2-x)^2}{L_2^2}\cdot\frac{dx}{EF} + \right.\\ &\left.\int_0^{L_3} 2\,.\,\frac{(L_3-x)^2}{L_3^2}\cdot\frac{dx}{EF}\right\} = +\,\frac{2\,S''\,(L_2+L_3)}{3EF}\end{aligned}\right\} \quad (48)$$

$$\left.\begin{aligned}S'''\,\Sigma^3\, u''\, u'''\, K = +\, S'''&\left\{\int_0^{L_3} 2\,.\,\frac{x\,(L_3-x)}{L_3^2}\cdot\frac{dx}{EF}\right\} =\\ &+\frac{S'''\,L_3}{3EF}\end{aligned}\right\} \quad (49)$$

Substituting these values, the second of equations (44) becomes

$$o = -\frac{q_2\, L_2^3 + q_3\, L_3^3}{12EFh} + \frac{S'\,L_2}{3\,EF} + \frac{2\,S''\,(L_2+L_3)}{3EF} + \frac{S'''\,L_3}{3EF} \quad (50)$$

The moment, M_2, at the first pier is $S'\,h$; that at the second pier is $M_3 = S''\,h$: hence (50) becomes

$$M_2\, L_2 + 2\, M_3\,(L_2 + L_3) + M_4\, L_3 = \tfrac{1}{4}\,(q_2\, L_2^3 + q_3\, L_3^3) \quad (51)$$

which is the general form of the theorem of three moments for the case of a uniform load.

The method above given clearly solves, then, the difficulty sometimes urged against the continuous girder, viz.: that it cannot be accurately calculated, taking account of a variable moment of inertia and a varying modulus of elasticity in different bars. As far as theoretical treatment goes, the continuous girder presents no difficulty, but practically the objections against it are so strong as to make it undesirable except in rare cases.

VIII. Historical and Critical.

The original articles upon the method which has formed the subject of the preceding pages are for the most part scattered through the various scientific periodicals; and the writer cannot pretend to be able to give a complete account of the history and bibliography of the subject; but with the hope that it may be of some interest and benefit to those who are less acquainted with the matter than himself, he ventures to add to the foregoing account the following brief notes.

The principle of virtual velocities, and the resulting principle that the work done by the outer forces, applied to any structure, equals that done by the inner forces, has long been recognized. It follows at once, too, from the principle of the conservation of energy. Its application to framed structures, however, is of comparatively recent date. The first writer who gave any such application, so far as I know, was Lamé, in his "Leçons sur la Théorie Mathématique de l'Elasticité des Corps Solides," published at Paris in 1866. In the seventh Leçon of this work Lamé applies the method to the determination of deflection, deducing, as we have done on a previous page, the equation

$$\frac{1}{2} P \Delta = \frac{s^2 l}{2FE},$$

P being the force applied to a given point of a frame, Δ the deflection of that point in the direction of P, s the stress caused thereby in a bar of length l and section F. From this follows

$$\Delta = \frac{t s l}{FE},$$

t being the stress when $P = 1$. If all the bars are elastic, the resulting value of Δ given by Lamé is substantially the same as our equation (3). He transforms his equation into another no more convenient for use, but puts $\frac{s}{P}$ constant, which is evidently incorrect, inasmuch as the same loading will not cause the maximum stresses in all the bars. He applies his method to a triangular frame, like our figure (5). Lamé does not seem to have fully grasped the importance and generality of the method, for he limits his discussion to finding the deflection of the point where a given load is applied, and does not show how the deflection of any point in any direction under any loading may be found.

The next author who discussed and applied the method, so far as I know, was Maxwell, who, in an article "On the Calculation of the

Equilibrium and Stiffness of Frames," in the "Philosophical Magazine," for April, 1864, treated the subjects of deflection and of frames with superfluous bars. He showed first the conditions under which frames are statically determined, deducing the equation $n = 2m - 3$; he then demonstrates a theorem which is essentially that embodied in the equation $\Delta = t \cdot \Delta l$, for any one bar; he then proceeds to discuss frames with superfluous bars, and deduces equations which are identical with those which we have given for this case; finally, he proceeds to find a formula for the deflection of a certain point of a Warren girder, finding separately that due to the web and that due to the chords, assuming in each case the stress per square inch to be the same in all the bars. This is of course incorrect; and in fact, it is useless to attempt to deduce any general formulæ of this kind. Maxwell discussed no other applications of the method, leaving untouched the important subject of the arch.

In the article "Bridges," in the Encyclopœdia Britannica, Professor Jenkin gave a short paragraph on the application of the method to arches hinged at the springing, and deduced an equation for the horizontal thrust identical with our equation (4). He gave no other applications.

To Professor Mohr, of Dresden, is due the credit of making the method known in Germany, as well as that of making several important additions. In the "Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover," for 1874 and 1875, will be found an article by him entitled "Beitrag zur Theorie des Fachwerks," in which he first discusses geometrically the condition under which frames are statically determined, treats the subject of deflection about as we have treated it, but adding nothing new to what previous writers had given, treats frames with superfluous bars, applying his results to several examples, and finally proceeds to treat the continuous girder. He gives the method which we have explained last (Fig. 11), and shows, as we have done, the agreement of the resulting formulæ with those obtained from the application of the Theorem of Three Moments. He states that, judging from several calculated examples, the assumption usually made, that the moment of inertia of the section of the girder is constant, is allowable. He calls attention to the difficulty attending the use of the method, viz., the tedious arithmetical calculations involved, and finally treats the whole subject graphically, developing a beautiful graphical method for finding the deflection of any point of

a girder, and giving a method of finding the stresses in the continuous girder by a process which consists in adding the ordinates of a polygon which he shows how to construct. Mohr calculates an example by this graphical method.

The arch with hinges at the springing was treated by Mohr in an article "Beitrag zur Theorie des Bogenfachwerkträger," in the same periodical, for 1874.

The next author to treat this method was Professor Winkler, of Berlin, in an article "Beitrag zur Theorie der Bogenträger," in the "Zeitschrift des Architekten- und Ingenieur-Vereins zu Hannover," for 1879. Winkler deduced our equation (4) for an arch hinged at springing, gave many other details connected with the calculation of such an arch, treated briefly the arch hinged at the crown, and also gave a treatment of the arch without hinges, which we have followed in the previous pages. In his book entitled "Innere Kräfte gerader Träger," Winkler discusses frames with superfluous bars, according to "Mohr's method," as he names it, though it really is Maxwell's. In fact, the matter seems to be generally attributed in Germany to Dr. Mohr, Maxwell's contributions being never referred to.

The only reference to the method in American literature, so far as I know, is in Professor Greene's book on Arches, chapter 12, where a method is given which, it is stated, is to be found in "The Engineer," for Feb. 10, 1873, and also in the Encyclopædia Britannica—article "Bridges." The first reference, however, is incorrect. Professor Greene's method, although amounting to the same as that given in Jenkin's article already referred to, is not exactly the same in principle; it is founded, not on the principle of virtual velocities, or of work, but on that of the instantaneous axis. The formula for H, however, is essentially identical with our equation (4). The detailed treatment of the arch by the same method, founded on the principle of the instantaneous axis, was given by Professor Fränkel, of Dresden, in "Der Civilingenieur," for 1875,* where the reference is made to the first theory of the framed arch hinged at springing, in which the change of length of each bar is taken into account, given by G. F. Schultze, in the "Zeitschrift des Vereins deutscher Ingenieure," for 1865, page 536. In this article the change of span is found by geometrical

*"Anwendung der Theorie des augenblicklichen Drehpunktes auf Bogenträger. Theorie des Bogenfachwerks mit zwei Gelenken."

methods, and the method used is complicated compared with that explained above.

Various other writers could be named who have written on this subject, but none who have added any new points, except in the details of application to particular cases.

The method which has been explained, supposes for its application the sections of all the bars of the frame to be given. In calculating a frame, these sections are what we wish to determine. The method given does not, therefore, dispense with a preliminary approximate calculation, according to the usual method, or others which may be deemed sufficiently accurate. It simply affords an exact solution of the problem, while the results given by the ordinary methods are more or less incorrect. In any case, the approximate sections must first be calculated. This may be easily done, in some cases, by assuming a hinge at some particular point; thus in the case of an arch with straight upper chord, curved lower chord, hinged at the abutments, and with a small depth at the crown, a hinge may be assumed at the latter point, and the stresses calculated approximately without resort to elastic conditions. In the case of the arch without hinges and with parallel chords, the usual method of computation, assuming a constant cross-section and neglecting the effect of the web on deflection, may be used as a first approximation; then the method which we have explained may be applied as many times as necessary, but usually one application will be sufficient to obtain the requisite accuracy.

At the commencement of this article we distinguished the elastic deflection from the non-elastic deflection. Thus far we have only considered the former. The question now arises, does the latter, which cannot be calculated, affect the accuracy of the method we have discussed? Unfortunately it does, for the equation (2) gives the deflection of any point due to a change of length Δl of one bar, due to any cause whatever. If the change of length is non-elastic and due to imperfect fitting, the deflection is non-elastic, but is none the less present. In the case of an arch, if any bar in the top chord (Fig. 7) becomes shorter on account of imperfect fit, the span is evidently increased and a horizontal thrust must exist, due to that cause alone, if the span is to be kept constant. If a frame is statically determined, both as regards the outer and inner forces, the non-elastic deflection is without effect on the stresses; for a consideration of deflection does not enter into their determination. Among non-elastic deflections we may include changes of length due

to changes of temperature, and to settling of the piers or abutments. If the non-elastic deflections are known, their effect may be calculated. The non-elastic deflections due to imperfect fitting of the parts, and to settling of piers and abutments can never be exactly known; that due to temperature may be allowed for as follows: Take first the case of the arch hinged at springing; if the temperature rises or falls by θ degrees, and the coefficient of expansion of the structure is a, then the change of span under vertical reactions would be $\pm L a \theta$. The horizontal thrust necessary to counterbalance this change of span is given by the equation.

$$\pm L a \theta = H \Sigma \frac{t^2 l}{F E}, \text{ or}$$

$$H = \pm \frac{L a \theta}{\Sigma \frac{t^2 l}{F E}} \qquad (52)$$

t being the stress produced in a bar by a force unity acting either outwards or inwards at the springing. The value of H calculated by equation (4) is liable to be increased or diminished by the value in equation (52), if θ is the change of temperature above or below a mean temperature, at which there is no stress due to this cause. As the value of θ may be 50 or 60 degrees, this change may become considerable. Other cases may be treated similarly, but it will be better to take into consideration the change of length $\theta a l$ of each bar. Thus equation (52) might be written

$$H = \pm \frac{\Sigma t l \theta a}{\Sigma \frac{t^2 l}{F E}} = \pm \theta a \frac{\Sigma t l}{\Sigma \frac{t^2 l}{F E}} \qquad (52a)$$

Similarly in any other case we have only to find the stresses due to changes of length $\theta a l$ of the bars.

The fact that statically undetermined systems cannot be exactly calculated, and are liable to have their calculated stresses changed by an uncertain amount on account of non-elastic deflections, constitutes the principal objection that can be urged against them. Difficulty of calculation would have little weight, if a saving of material were to be effected by their use; but the uncertainty attending them renders necessary a larger factor of safety and more carefully constructed piers and abutments, while the true state of stress can never be exactly known. The disfavor into which continuous girders have fallen in almost all countries except France is, therefore, no doubt justified; and

of the various forms of the arch, that with three hinges is to be preferred. If there is one element which a structure should possess, it is certainty in regard to the forces which are exerted in it. No refined calculations as to saving of material can be weighed in the balance against indeterminate stresses. In a few cases it can be shown that the uncertainty is small—that the limits of error are narrow; in these cases practical considerations may point to the adoption of a statically undetermined system. While the writer, therefore, is no advocate of the indiscriminate use of the statically undetermined systems—of the continuous girder, and of arches with fewer than three hinges—he nevertheless hopes in these pages to have brought to the attention of some who may have been unacquainted with them, some methods and considerations which are as beautiful as they are valuable and interesting.

ERRATA—Page 112, 1st line from bottom, for $H_2 L f V_2$ read $H_2 = f V_2$. Page 115, 13th line from top, for $\frac{Z}{h}$ read $\frac{z}{h}$. Page 196, 13th line from top, for $\Sigma_r \frac{h_r S l}{F E}$ read $\Sigma_r \frac{v_r S l}{F E}$. Page 198, 4th line from bottom, for x read d. Page 201, 7th line from top, for R_n read $- R_n$. Page 204, 6th line from top, for $u^{2\prime\prime}$ read $u_2{}''$.

Observations of the Solar Spectrum.—One of the objects of Langley's expedition to Mount Whitney, in 1881, was to obtain a new determination of the solar constant, or the quantity of heat sent to the earth, and to ascertain incidentally the laws of the absorption of solar rays by the atmosphere. Pouillet's classical value is about 1·7 calories. Later determinations tend to increase this value; those of Soret, Crova, and Violle indicate from 2·2 to 2·5 calories. On account of the great number of observations and the long calculations which they require, Langley has not yet given a final estimate, but he finds that it will be about three calories; in other words, were it not for our atmosphere, the solar rays would heat one gramme of water three degrees C. per minute, for each square centimetre of the earth's surface which was normally exposed to it. His observations show that only a fourth of the energy which vivifies the world is found in the visible and ultra violet portions of the spectrum. On eliminating the effects of atmospheric absorption, he infers that the absolute color of the photosphere is blue.—*Comptes Rendus*, xcv, 482. C.

THE ATTITUDES OF ANIMALS IN MOTION.

By EADWEARD MUYBRIDGE, of San Francisco.

[A lecture delivered before the Franklin Institute, February 13th, 1883.]

The problem of animal mechanism has engaged the attention of mankind during the entire period of the world's history.

Job describes the action of the horse; Homer, that of the ox; it engaged the profound attention of Aristotle, and Borelli devoted a lifetime to its attempted solution. In every age and in every country, philosophers have found it a subject of exhaustless research. Marey, the eminent French savant of our own day, dissatisfied with the investigations of his predecessors, and with the object of obtaining more accurate information than their works afforded him, employed a system of flexible tubes, connected at one end with elastic air-chambers, which were attached to the shoes of a horse; and at the other end with some mechanism, held in the hand of the animal's rider. The alternate compression and expansion of the air in the chambers caused pencils to record upon a revolving cylinder the successive or simultaneous action of each foot, as it correspondingly rested upon or was raised from the ground. By this original and ingenious method, much interesting and valuable information was obtained, and new light thrown upon movements until then but imperfectly understood.

While the philosopher was exhausting his endeavors to expound the laws that control and the elements that effect the movements associated with animal life, the artist, with a few exceptions, seems to have been content with the observations of his earliest predecessors in design, and to have accepted as authentic without further inquiry, the pictorial and sculptural representations of moving animals bequeathed from the remote ages of tradition.

When the body of an animal is being carried forward with uniform motion, the limbs in their relations to it have alternately a progressive and a retrogressive action, their various portions accelerating in comparative speed and repose as they extend downwards to the feet, which are subjected to successive changes from a condition of absolute rest, to a varying increased velocity in comparison with that of the body.

The action of no single limb can be availed of for artistic purposes without a knowledge of the synchronous action of the other limbs; and to the extreme difficulty, almost impossibility, of the mind being

capable of appreciating the simultaneous motion of the four limbs of an animal, even in the slower movements, may be attributed the innumerable errors into which investigators by observation have been betrayed. When these synchronous movements and the successive attitudes they occasion are understood, we at once see the simplicity of animal locomotion, in all its various types and alternations. The walk of a quadruped being its slowest progressive movement would seem to be a very simple action, easy of observation and presenting but little difficulty for analysis, yet it has occasioned interminable controversies among the closest and most experienced observers.

When, during a gallop, the fore and hind legs are severally and consecutively thrust forwards and backwards to their fullest extent, their comparative inaction may create in the mind of the careless observer an impression of indistinct outlines; these successive appearances were probably combined by the earliest sculptors and painters, and with grotesque exaggeration adopted as the solitary position to illustrate great speed. Or, as is very likely, excessive projection of limb was intended to symbolize speed, just as excess in size was an indication of rank. This opinion is to some extent corroborated by the productions of the Grecian artists in their best period, when their heroes are represented of the same size as other men, and their horses in attitudes more nearly resembling those possible for them to assume. The remarkable conventional attitude of the Egyptians, however, has, with few modifications, been used by artists of nearly every age to represent the action of galloping, and prevails without recognized correction in all civilized countries at the present day.

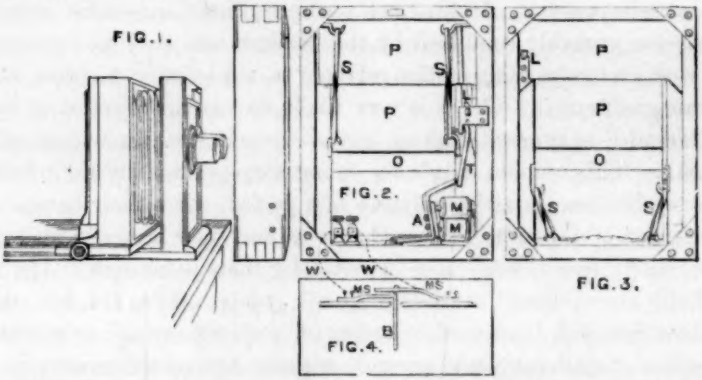
The ambition and perhaps also the province of art in its most exalted sense, is to be a delineator of impressions, a creator of effects, rather than a recorder of facts. Whether in the illustrations of the attitudes of animals in motion the artist is justified in sacrificing truth, for an impression so vague as to be dispelled by the first studied observation, is a question perhaps as much a subject of controversy now as it was in the time of Lysippus, who ridiculed other sculptors for making men as they existed in nature; boasting that he himself made them as they ought to be.

A few eminent artists, notable among whom is Meissonier, have endeavored in depicting the slower movements of animals to invoke the aid of truth instead of imagination to direct their pencil, but with little encouragement from their critics; until recently, however, artists

and critics alike have necessarily had to depend upon their observation alone to justify their conceptions or to support their theories.

Photography, at first regarded as a curiosity of science, was soon recognized as a most important factor in the search for truth, and its more popular use is now entirely subordinated by its value to the astronomer, the anatomist, the pathologist, and other investigators of the complex problems of nature. The artist, however, still hesitates to avail himself of the resources of what may be at least acknowledged as a handmaiden of art, if not admitted to its most exalted ranks.

Having devoted much attention in California to experiments in instantaneous photography, I, in 1872, at the suggestion of the editor of a San Francisco newspaper, obtained a few photographic impressions of a horse during a fast trot.



At this time much controversy prevailed among experienced horsemen as to whether all the feet of a horse while trotting were entirely clear of the ground at the same instant of time. A few experiments made in that year proved a fact which should have been self-evident.

Being much interested with the experiments of Professor Marey, in 1877, I invented a method for the employment of a number of photographic cameras, arranged in a line parallel to a track over which the animal would be caused to move, with the object of obtaining, at regulated intervals of time or distance, several consecutive impressions of him during a single complete stride as he passed along in front of the cameras, and so of more completely investigating the successive attitudes of animals while in motion than could be accomplished by the system of M. Marey.

I explained the plan of my intended experiments to a wealthy res-

ident of San Francisco—Mr. Stanford—who liberally agreed to place the resources of his stock-breeding farm at my disposal, and to reimburse the expenses of my investigations, upon condition of my supplying him, for his private use, with a few copies of the contemplated results. The apparatus used and its arrangement will be better understood by a reference to the accompanying drawings.

Fig. 1. A photographing lens, and camera containing a sensitised plate; and side view of electro-exposor placed in front of camera.

Fig. 2. Back view of electro-exposor. Two shutters P P, each comprising two panels, with an opening O between them, are adjusted to move freely up and down in a frame; they are here arranged ready for an exposure, and are held in position by a latch L and trigger T, all light being excluded from the lens. A slight extra tension of the thread B, Fig. 4, will cause a contact of the metal springs M S, and

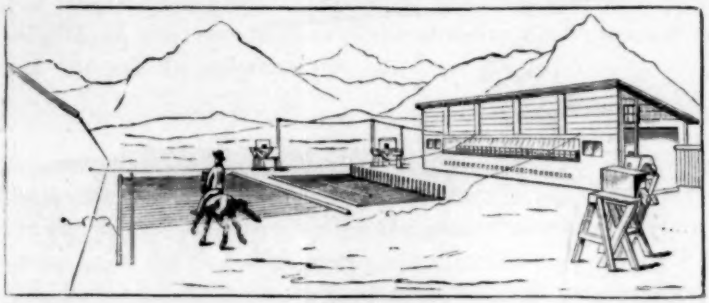


Fig. 5.

complete a circuit of electricity through the wires W W and the electro-magnet M; the consequent attraction causes the armature A to strike the trigger, the latch is released, the shutters are drawn respectively upwards and downwards by means of the rubber springs S S, and light is admitted to the sensitised plate while the openings in the shutters are passing each other in front of the lens.

Fig. 3. Front view of electro-exposor after exposure of the plate.

Fig. 5. General view of studio, operating track, and background. In the studio are arranged 24 photographing cameras; at a distance of 12 inches from the centre of each lens an electro-exposor is securely fixed in front of each camera. Threads 12 inches apart are stretched across the track (only two of which are introduced in the engraving), at a suitable height to strike the breast of the animal experimented with, one end of the thread being fastened to the background, the other to the spring, Fig. 4, which is drawn almost to the point of contact.

The animal in its progress over the track will strike these threads in succeseion, and as each pair of strings is brought into contact, the current of electricity thereby created effects a photographic exposure, as described by Figs. 2 and 4; and each consecutive exposure records the position of the animal at the instant the thread is struck and broken.

For obtaining successive exposures of horses driven in vehicles, one of the wheels is steered in a channel over wires slightly elevated from the ground; the depression of each wire completes an electric circuit, and effects the exposures in the same manner as the threads.

Fig. 6. Operating track, covered with corrugated India rubber, and marked with transverse lines 12 inches apart. Each line is numbered, for the purpose of more readily ascertaining the length of the animal's

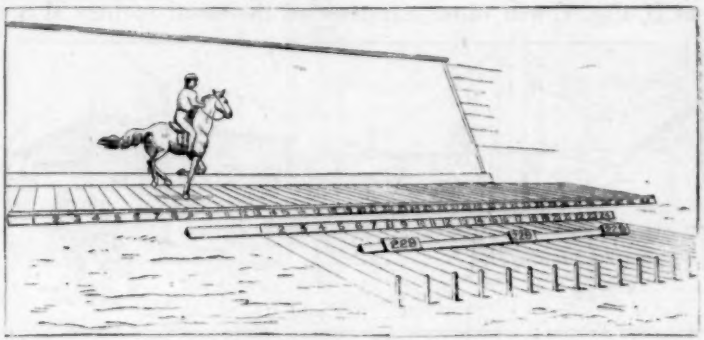


Fig. 6.

stride. On one side of the track, and opposite to the battery of cameras, a white background is erected at a suitable angle.

The camera in which any one negative in a series of exposures is made is designated on that negative by the parallel direction of the vertical stake with the horizontal line extending to the corresponding number immediately opposite. The discriminating number of each series is marked on each negative by the large numbers—229, for example—which are changed for each movement illustrated.

For recording the successive attitudes of animals not under control, an apparatus is used, comprising a cylinder, around which are spirally arranged a number of pins; upon the cylinder being set in motion through gearing connected with a spring or weight, these pins are consecutively brought into contact with a corresponding number of metal springs; a succession of electric currents is thereby created which act

through their respective magnets attached to the electro-exposors at regulated intervals of time. The cylinder is put in motion either by bringing it into gearing with other parts of the apparatus already in motion; or by releasing a break with the hand, or by the action of some object at a distance by means of an electric current.

This apparatus is principally used for illustrating the flight of birds, the motions of small animals, and changes of position without continuous progressive motion, such as occur during wrestling or turning a somersault; when the cameras are directed towards the place where the movements are being executed.

The boxes outside the studio (Fig. 5) contain cameras and electro-exposors for obtaining synchronous exposures of a moving object from different points of view.

The following analyses of some of the movements investigated by the aid of electro-photographic exposures, are rendered more perfectly intelligible by the reproductions of the actual motions projected on the screen through the zoöpraxiscope.

THE WALK.

Selecting the horse for the purposes of illustration, we find that during his slowest progressive movement—the walk—he has always two, and, for a varying period, three feet on the ground at once. With a fast-walking horse the time of support upon three feet is exceedingly brief; while during a very slow walk all four feet are occasionally on the ground at the same instant.

The successive order of what may be termed foot fallings are these. Commencing with the landing of the left hind foot, the next to strike the ground will be the left fore foot, followed in order by the right hind and right fore foot. So far as the camera has revealed, these successive foot fallings during the walk are invariable, and are probably common to all quadrupeds. But the time during which each foot, in its relation to the other feet, remains on the ground, varies greatly with different species of animals, and even with the same animal under different conditions. During an ordinary walk, at the instant preceding the striking of the left hind foot, the body is supported on the right laterals, and the left fore foot is in act of passing to the front of the right fore foot. The two hind feet and the right fore foot immediately divide the weight. The right hind foot is now raised, and the left hind with its diagonal fore foot sustains the body; the left fore next touches the

ground, and for an instant the animal is again on three feet; the right fore foot is immediately raised and again the support is derived from laterals—the left instead of as before the right. One-half of the stride is now completed, and a similar series of alternations, substituting the right feet for the left, completes the other half. These movements will perhaps be more readily understood by a reference to the longitudinal elevation, Fig. 7, No. 1, which illustrates some approximate relative positions of the feet of a rapid walking horse, with a stride of 5 feet 9 inches. The positions of the feet indicated in this, and also in the other strides illustrated in Fig. 7, are copied from photographs, and from them we learn that during an ordinary walk the consecutive supporting feet are—

1. The left hind and left fore—*laterals.*
2. Both hind, and left fore.
3. Right hind and left fore—*diagonals.*
4. Right hind and both fore.
5. Right hind and right fore—*laterals.*
6. Both hind, and right fore.
7. Left hind and right fore—*diagonals.*
8. Left hind and both fore.

Commencing again with the first position; it is thus seen that when a horse during a walk is on two feet, and the other two feet are suspended between the supporting legs, the suspended feet are laterals. On the other hand, when the suspended feet are severally in advance of and behind the supporting legs, they are diagonals.

These invariable rules seem to be neglected or entirely ignored by many of the most eminent animal painters of modern times.

THE TROT.

By some observers the perfect trot is described as an absolutely synchronous movement of the diagonal feet. This simultaneous action may be considered desirable, but it probably never occurs.

Sometimes the fore foot will be raised before the diagonal hind foot, sometimes afterwards; but in either instance, the foot raised first will strike the ground first; repeated experiments with many racing and other trotting horses confirmed this want of simultaneity. Selecting for an example of the trot a horse making a stride of 18 feet in length, we find that at the instant his right fore foot strikes the ground, the left hind foot is a few inches behind the point where it will presently

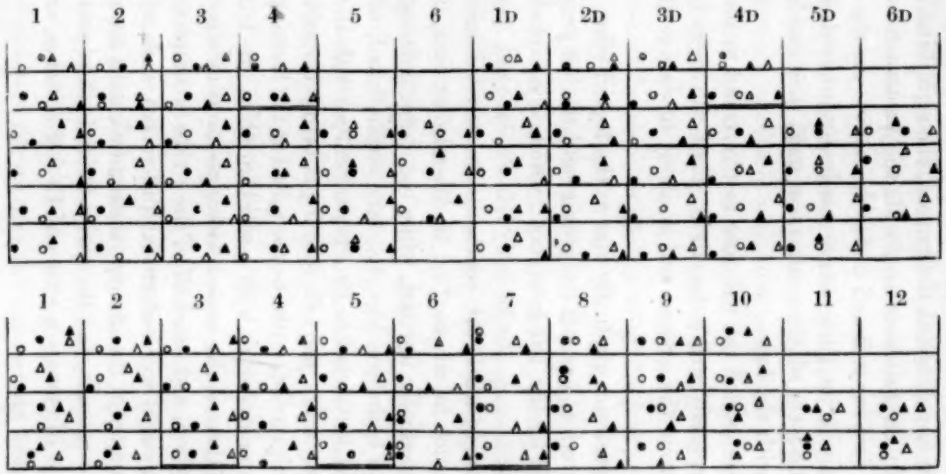
LONGITUDINAL ELEVATION OF SOME CONSECUTIVE POSITIONS OF THE FEET OF HORSES DURING VARIOUS MOVEMENTS.

KEY.

	Rt.	*Left.*
Hind Feet	●	○
Fore Feet	▲	△
Line of Ground	●○	

Each line illustrates a single complete stride. The comparative distances of the feet from each other, or from the ground, are approximate; not to scale. Direction of movement ——>

Action.	Length of Stride. ft.	in.
1. Walking	5	9
2. Trotting	7	6
3. "	17	6
4. "	18	3
5. Ambling	10	3
6. Racking	12	6
7. Cantering	10	3
8. Galloping	11	9
9. "	19	9
10. Galloping, a conjectural stride of 22 feet or more.		



strike at about 38 or 40 inches to the rear of the fore foot. When both feet have reached the ground, the right hind leg is stretched back almost to its fullest extent, with the pastern nearly horizontal, while the left fore leg is flexed under the body. As the legs approach a vertical position the pasterns are gradually lowered, and act as springs to break the force of the concussion until they are bent nearly at right angles with the legs.

At this period the left fore foot is raised to its greatest height, and will frequently strike the elbow, while the right hind foot is but little raised from the ground and is about to pass to the front of the left hind.

The pasterns gradually rise as the legs decline backwards until the right fore foot has left the ground and the last propelling force is being exercised by the left hind foot; which accomplished, the animal is in mid air.

The right hind foot continues its onward motion until it is sometimes much in advance of its lateral fore foot, the former, however, being gradually lowered, while the latter is being raised. The right hind and both fore legs are now much flexed, while the left hind is stretched backward to its greatest extent with the bottom of the foot turned upwards, the left fore leg is being thrust forwards and gradually straightened, with the toe raised as the foot approaches the ground; which accomplished, with a substitution of the left limbs for the right we find them in the same relative positions as when we commenced our examination, and one-half of the stride is completed.

With slight and immaterial differences, such as might be caused by irregularities of the ground, these movements are repeated by the other pair of diagonals, and the entire stride is then complete.

Line 4 illustrates a stride of 18 feet 3 inches, and the order of supporting feet are:—

1. The right fore foot.
2. The left hind and right fore feet.
3. The left hind foot.
4. Without support.
5. The left fore foot.
6. The right hind and left fore feet.
7. The right hind foot.
8. Without support.

It appears somewhat remarkable that until the results of M. Marey's

experiments and of those obtained by electro-photography were published, many experienced horsemen were of opinion that during the action of trotting at least one foot of a horse was always in contact with the ground.

If the entire stride of a trotting horse is divided into two portions, representing the comparative distances traversed by the aggregate of the body while the feet are in contact with, and while they are entirely clear of, the ground; the relative measurements will be found to vary very greatly, they being contingent upon length of limb, weight, speed, and other circumstances.

Heavily built horses will sometimes merely drag the feet just above the surface, but, in every instance of a trot, the *weight* of the body is really unsupported twice during each stride (see stride 2, positions 4 and 4D). It sometimes happens that a fast trotter, during the two actions of a stride, will have all his feet clear of the ground for a distance exceeding one-half of the length of the entire stride; this elasticity of movement is however exceptional.

The action of a fast-trotting horse while drawing a vehicle is very different from his action under the saddle; in the latter case, the hind legs are kept thrust back for a longer period, and their final forward movement is much more rapid.

THE AMBLE.

Assuming our observation of this movement to commence when, during a stride of about 10 feet, the left hind foot has just struck the ground slightly to the rear of where the right fore foot is resting; the left fore leg will be well advanced but still flexed, with the toe pointed downwards, and the right hind foot having been the last to leave the ground, will be thrust backwards with the pastern nearly horizontal.

As the right fore foot leaves the ground, the left fore leg is gradually straightened during its thrust forwards; the right hind foot in the meantime is gradually advancing, and the horse is supported on the left hind foot alone.

The left fore foot is now brought to the ground, and the body rests on the left laterals, with the right laterals suspended between them.

As the left fore leg attains a vertical position, its lateral leaves the ground, and the support of the body devolves on the left fore foot alone, the right fore leg being considerably flexed, with the foot in advance of the left fore leg.

The right hind foot now strikes the ground, and one-half of the stride is accomplished; these movements are repeated with a change of the limbs for the remaining portion of the stride, and the horse is again in the position in which we first observed him.

We shall see by reference to stride No. 5 the consecutive supporting feet to be:

1. The left hind foot.
2. The left hind and left fore feet—*laterals.*
3. The left fore foot.
4. The left fore and right hind feet—*diagonals.*
5. The right hind foot.
6. The right hind and right fore feet—*laterals.*
7. The right fore foot.
8. The right fore and left hind feet—*diagonals.*

The right fore foot being raised, the horse is again in the first position.

The amble and the walk are the only regular progressive movements of the horse wherein the body is never without the support of one or more legs, in all others the weight is entirely off the ground for a longer or shorter period.

THE RACK OR PACE.

The rack differs from the trot in the nearly synchronous action of the *laterals* instead of the *diagonals.*

In some countries the rack is naturally adopted by the horse as one of his gaits, but it is probably caused by the effects of training exercised over many generations of his ancestors.

The movements already described are regular in their action, and a stride may be divided into two parts, which are essentially similar to each other.

THE CANTER

and the gallop, however, cannot be so divided, and a complete stride in either of those gaits is a combination of several different movements.

The canter is usually regarded as a slow gallop, probably from the facility with which a change from one gait to the other can be effected; an important difference will, however, be observed.

Assuming a horse after his propulsion through the air, during a stride of 10 feet, to have just landed on his left hind foot, the right hind foot will be on the point of passing to the front of the left. The left fore leg will be thrust forward and nearly straight, while the right

fore leg will be flexed with the foot elevated about 12 inches from the ground, and somewhat behind the vertical of the breast. The left fore foot being brought to the ground, the body is supported by the laterals; the right hind foot is, however, quickly lowered, and performs its share of support. The left hind foot is then raised, and the right hind and left fore legs assume the weight, the former being nearly vertical, and the latter inclined well back, the right fore foot is thrust well forward, and is just about to strike the ground; when it does, three feet again share the support, they being the two fore and the right hind. The left fore foot now leaves the ground, and we again find the support furnished by the laterals, the right instead of, as before, the left.

The right hind foot is raised when the right fore leg becomes vertical; this latter, which now sustains the entire weight, gives the final effort of propulsion, and the body is hurled into the air.

The descent of the left hind foot completes the stride, and the consecutive movements are repeated.

In stride No. 7 we learn that during the canter the support of the body is derived from--

1. The left hind foot.
2. The left hind and left fore feet—*laterals.*
3. Both hind and the left fore feet.
4. The right hind and left fore feet—*diagonals.*
5. The right hind and both fore feet.
6. The right hind and right fore feet—*laterals.*
7. The right fore foot alone, on which he leaves the ground.

THE GALLOP OR RUN.

This movement has in all ages been employed by artists to convey the impression of rapid motion, although, curiously enough, the attitude in which the horse has been almost invariably depicted is one which is impracticable during uniform progressive motion.

When during a rapid gallop, with a stride of 20 feet, a horse after his flight through the air lands on his left hind foot, the right hind will be suspended over it at an elevation of 12 or 15 inches, and several inches to the rear of and above it the sole of the right fore foot will be turned up almost horizontally, the left fore leg is flexed with the foot under the breast at a height of 18 or 20 inches.

The right hind foot strikes the ground some 36 inches in advance of the left hind, each as they land being forward of the centre of gravity.

The body is now thrust forward, and while the right hind pastern is still almost horizontal, the left hind foot leaves the ground. At this time the left fore leg is perfectly straight, the foot, with the toe much higher than the heel, is thrust forward to a point almost vertical with the nose, and at an elevation of about 12 inches the right fore knee is bent at right angles, and the foot suspended under the breast at several inches greater elevation than the left fore foot.

The left fore foot now strikes the ground, 96 inches in advance of the spot which the right hind foot is on the point of leaving, and for a brief space of time the diagonals are upon the ground together. The left fore leg, however, immediately assumes the entire responsibility of the weight, and soon attains a vertical position, with its pastern at right angles to it.

In this position the right hind foot is thrust back to its fullest extent, at an elevation of 12 or 14 inches, with the pastern nearly horizontal. The left hind foot is considerably higher and somewhat more forward; the right fore leg is straight, stretched forward, with the foot about 15 inches from the ground, and almost on a perpendicular line from the nose. The right fore foot strikes the ground 48 inches in advance of the left fore, which, having nearly performed its office, is preparing to leave the ground; the animal will then be supported on the right fore foot alone, which immediately falls well to the rear of the centre of gravity, which is sometimes passed by the left hind foot at a height of about 12 inches; the right hind foot is some distance in the rear, and the left fore foot, at a height of 24 inches, is suspended somewhat in advance of its lateral.

In this position the horse uses the right fore foot for a final act of propulsion, and is carried in mid air for a distance of 60 inches, after which the left hind foot descends, the stride is completed, and the consecutive motions renewed.

The measurements and positions herein given do not pretend to exactness, as they must depend to some extent upon the capability, training, and convenience of the animal; but they may be accepted as representing an average stride of 20 feet with a horse in fair condition for racing.

From this analysis it will be seen, by reference to stride 9, that a horse, during an ordinary gallop, is supported consecutively by:

1. The left hind foot,
2. Both hind feet,

3. The right hind foot,
4. The right hind and left fore feet,
5. The left fore foot,
6. Both fore feet,
7. The right fore foot,

with which he leaves the ground, while the only position in which we find him entirely without support is when all the legs are flexed under his body.

It is highly probable, however, that more exhaustive experiments with long-striding horses in perfect training, will discover there is sometimes an interval of suspension between the lifting of one fore foot and the descent of the other; and also between the lifting of the second hind foot which touches the ground, and the descent of its diagonal fore foot (see imaginary stride 10). Should this latter be the case, it will, from the necessary positions of the other limbs, afford but a very shadowy pretext for the conventional attitude used by artists to represent a gallop. It is extremely doubtful if there can be any interval of suspension between the lifting of one hind foot and the descent of the other, no matter what the length of stride.

Many able scientists have written on the theory of the gallop, but I believe Marey was the first to demonstrate, that in executing this movement, the horse left the ground with a fore foot and landed on a hind foot.

THE LEAP.

There is little essential difference in general characteristics of either of the several movements that have been described, but with a number of experiments made with horses while leaping, no two were found to agree in the manner of execution. The leap of the same horse at the same rate of speed, with the same rider, over the same hurdle, disclosed much variation in the rise, clearance, and descent of the animal. Apart from this, the horses were not thoroughly trained leapers, and the results are perhaps not representative of those that would be obtained from the action of a well-trained hunting horse. A few motions were, however, invariable. While the horse was raising his body to clear the hurdle, one hind foot was always in advance of the other, and exercised its last energy alone.

On the decent, the concussion was always received by one fore foot, supported by the other more or less rapidly, and sometimes as much as 30 inches in advance of where the first one struck, followed by the

hind feet also, with intervals of time and distance between their several falls. It is highly probable future experiments will prove these observations to be invariable in leaping.

It is highly probable that these photographic investigations, which were executed with wet collodion plates with exposures not exceeding in some instances the one five-thousandth part of a second, will dispel many popular illusions as to gait, and that future and more exhaustive experiments, with all the advantages of recent chemical discoveries, will completely unveil to the artist all the visible muscular action of men and animals during their most rapid movements.

The employment of automatic apparatus for the purpose of obtaining a regulated succession of photographic exposures is too recent for its value to be properly understood, or to be generally used for scientific experiment; at a future time, the pathologist, the anatomist, and other explorers for hidden truths will find it indispensable for their complex investigations.

CHARCOAL AS APPLIED TO THE DEPOSITION OF GOLD FROM CHLORINE SOLUTIONS, AND ITS PERFECT SEPARATION FROM COPPER AND OTHER IMPURITIES.

By William Morris Davis.

[A paper read at the Stated Meeting of the Franklin Institute, March 21, 1883.]

As preliminary to the subject, and necessary to a just appreciation of its value in utilizing the refractory ores of gold, it may be remarked that in our country there exist immense amounts of auriferous sulphides, and arsenides, which have not been deemed available on account of their refractory nature, or their low value in gold.

Smelting has only been applied to such ores when they carried a comparatively high value in gold. Kerl teaches that "ores containing combined gold to the amount of $20 per ton cannot be profitably fused with lead, even could they be raised without mining cost."

By chlorination, ores containing combined gold to the amount of $10 per ton can be profitably worked, mining cost included.

This process has not found general application for reasons which will be considered hereafter.

Chlorination of the refractory ores involves three distinct operations, viz.:

1. Roasting, to expel the volatile constituents of the ores, and to oxidize the metallic elements other than gold.

2. Dissolving the gold by means of chlorine, preferably by the Mears process, and by filtration or leaching, separating the auriferous and cuprous solution from the sands.

3. Precipitation of the gold by salt of iron, or sulphuretted hydrogen, or the deposition of the gold, and its complete separation from attendant impurities by percolation through granulated vegetable charcoal.

This last method has been the subject of a United States Patent, and its chemical reactions have been examined by George A. Koenig, and published in the INSTITUTE JOURNAL, May, 1882.

It is herein purposed to consider this new method, in its technical application to enlarged operations in commercially obtaining gold from its solutions, which is attended by phenomena that would not be considered by the experimentalist in the limited operations of the laboratory. Also, to compare the new deposition of gold with the old methods of precipitation.

It has been known to a few antiquarian searchers in chemical records, that amongst the multitude of substances, inorganic and organic, which decompose an acid solution of terchloride of gold, carbon was named by Count Rumford (Sir Benjamin Thompson), as possessing this property. But it was under certain conditions only that he observed it to act; for, he says, "recently ignited charcoal separates gold only in sunshine or a temperature of 109°F."

Further research showed that in the presence of either "sunshine" or a temperature of 109°, gold will be deposited from its solution in the *absence* of carbon.

Thus Kane teaches that "when chlorine water is exposed to the light it is gradually decomposed, chloride of hydrogen being formed, and oxygen set free."

He further teaches that heat has the effect of decomposing such solutions with like results.

Should gold be present, it will be precipitated in proportion as the chlorine is converted into chloride of hydrogen for the reason that gold is insoluble in this acid.

When it was thus shown that the conditions, light and heat, as

named by Rumford, were sufficient for the deposition of gold from its solution, then his supposed discovery was consigned to the limbus of curious and useless chemical observations.

This property of carbon is but casually mentioned by other authors; but it is nowhere taught that carbon is distinguished by a remarkable energy, or as differing from the crowd of organic substances with which it is classed.

Neither is it suggested in any scientific work that the deposition was sufficient to be of commercial value, and, so far as known, no use has ever been made of such knowledge in the commercial separation of gold from its solutions. Nor has it been employed in the metallurgy of gold except as a fuel.

On the contrary, when the attention of chemical experts was first called to the claims of the discoverer, they were discredited by most, and thought by others, deservedly high in authority, to "run counter to well known principles and chemical laws;" even at this time well informed minds are at a loss to account for the remarkable energy of this new agent in reducing gold to a metallic state from its solutions; also the remarkable fact that it is inert towards other metallic and mineral constituents of the solution; thus serving the double purpose of depositing and refining the gold.

Neither are many chemists prepared to admit the following conclusions, derived from experimental observations and investigation during many months of practical operations on a scale, varying from the experiment of ounces in the laboratory, to nearly two thousand tons of ore in the reduction works, in which, over 600,000 gallons of a terchloride solution of gold was subjected to the action of charcoal, and $11,152 in gold retained.

The following formula is offered as explanatory of the reactions attending the deposition of gold from a chlorine solution:

$$2AuCl_3+3C+6HO=6HCl+3CO_2+2Au \text{ free.}$$

This hypothesis is strengthened by the observed action of chlorine on other substances.

Thus Kane teaches that, "Chlorine has a powerful affinity for hydrogen, and when brought in contact with other bodies, in the presence of water, will decompose the water by combining with the hydrogen forming ClH, and liberating oxygen. Thus he says, substances are frequently oxidized by chlorine to a higher degree than by nitric acid."

Selenious acid (SeO_2) and chlorine, in the presence of water are converted into selenic acid (SeO_3) and ClH, thus:—

$$SeO_2 + Cl + HO = SeO_3 + ClH.$$

Reasoning from analogy, we may explain the reactions attending the deposition of gold, by substituting carbon for selenious acid; in which case the carbon becomes oxidized at the expense of the water, forming carbonic acid (CO_2), the liberated hydrogen uniting with the chlorine, forming ClH.

That such are the reactions, may be assumed, *a priori*, because all the elements involved are satisfied according to their known affinities, and form definite compounds, leaving the gold free.

It therefore follows, that the deposition of the gold is caused by the conversion of the chlorine (which is a solvent of the metal) into chlorhydric acid, (in which gold is insoluble) and is not occasioned by any particular affinity of the carbon for the gold; and it also follows that copper or other mineral constituents of the solution, will be retained in solution by the ClH, because soluble by it.

That the chlorine is converted into muriatic acid (ClH) was shown by the following experiment.

After a filter containing 80 gallons of coal had passed 8,750 gallons of a strong chlorine solution, there were taken equal portions of the solution, the one from the surface, the other from the lower faucet, after passage through the coal.

In the first sample, the chlorine acted powerfully on the senses; being quite suffocating, in the second no odor was perceptible, even on the application of heat.

By the addition of nitrate of silver, to each sample, and collecting the precipitated chloride of silver, washing and drying with due precautions, the weights of the two agreed; the one determining the sensible chlorine in the original solution, the other the insensible chlorine as existing in the hydrochloric acid formed by the passage over the charcoal.

That the gold disappeared from the solution with the conversion of chlorine, is shown in the following extract from a report on the process by Prof. Endlich, of Washington:

"In order to test the efficacy of the process," he says, "I took, systematically, samples from the receiving tanks, from the collecting tanks, from the pipe which carried the solution to the filter, and from the

stop-cock through which the liquid passed after the solution had been in contact with the charcoal."

"The unvarying result of these repeated tests may be summed up briefly."

"While I never failed to get copious precipitates of gold from the solution in the tanks, and from that taken from the faucet through which it flowed into the carbon filter, I never obtained the slightest gold precipitate from the same liquid after it had passed through the charcoal."

"The experiments I witnessed prove beyond a doubt, the fact, that gold is dissociated by the contact of terchloride solution with carbon and is deposited upon the latter."

"That this deposition is complete is shown by the total absence of gold from the liquid after it had passed through the charcoal filter."

"Briefly restating what has been said at greater length, I would repeat,—the charcoal filter as here used, is entirely sufficient to precipitate from a terchloride solution all the gold contained therein." In laboratory practice, it has been found that proto-sulphate of iron is a most delicate test of the presence of gold in its solution, and is the usual precipitant employed; either this salt or sulphuretted hydrogen amply meets the requirements of the chemist in his researches; for, in the minute proportions therein employed, no account is made of the proportions of the reagents used, and, where the separation of the precipitate from the supernatant fluid is entirely within control, and the time employed is of no especial moment, these reagents suffice.

But, when the ounces employed by the chemist, swell to tons in the hands of the metallurgist, and the solutions grow to unwieldy proportions; when the saline constituents of his solutions vary with the ores operated upon, and when the solution is highly saturated with chlorine (as is the case where it is formed under pressure), or, when the ores are of such low grade, that, to make them available, the costs must be reduced to the lowest; then, the unnoticed factors of the laboratory swell to formidable proportions, and stand, an almost insurmountable bar to the chlorinating process on a business scale. Therefore, chlorination has been confined to quite limited operations, whilst its excellence, as a solvent of the gold, is unquestioned.

It must be admitted that in laboratory experiments, carbon is as inconvenient and impracticable, as the above reagents have proved in operations upon an extended scale.

WHAT IS CLAIMED FOR THE CHARCOAL PROCESS.

1. Commercially depositing gold from its solution by subjecting the same to the action of carbon.

2. Depositing gold from its solution by causing a current of such solution to flow past or through carbon.

3. The process of obtaining gold from its solution by bringing said solution in contact with carbon, and thereby depositing the gold upon it, and of subsequently obtaining the gold from the carbon by incineration, or other equivalent means.

By charcoal the gold is deposited and retained in metallic form on fixed surfaces, as the solution is passing from the mill at the rate of 80 gallons per hour through 80 gallons of coal or, extending over the 24 hours, equal to disposing of the solutions from 6·4 tons of ore for a single filter. By a duplication of the filters, provision may be made for chlorination, equal to the utmost production of a large mine.

By the older and prevalent methods the gold is precipitated in an impalpable powder, in a large volume of fluid of a density of 3° to 5° Beaumé.

By the carbon method, the gold is securely held against waste or loss until the coal is reduced to ash, preparatory to the melting into ingots.

By the old methods, it is to be obtained only by the slow subsidence of the powder to the bottom of the precipitation tanks, to be subsequently collected by decantation or tedious filtrations.

It is proposed to substitute the continuous passage of the solution through coal by a flow regulated with the nicest precision to the requirements of the works, for the intermittent and complex operations incident to precipitation by the old methods, to wit:

1. Accumulation in precipitation tanks.

2. Precipitation, with chance of waste in excess of precipitant.

3. Subsidence, with great loss in time, on account of the great volume of solutions and their density.

4. Decanting, or syphoning, of the supernatant liquid, with probable loss from incomplete subsidence of the gold.

5. Filtration of the fluid contents of tanks, after decanting as far as is safe.

6. Voluminous contents of filters from the foreign substances thrown down with the gold, which embarrass the after-crucible operations.

Louis Blanding, of San Francisco, writes: "I am well, I may say painfully, aware of the defect and shortcoming of the present mode of

precipitation, either by the proto-sulphate of iron, or by the use of sulphuretted hydrogen, for I have for many years faced the difficulties in my own works, and tried in many ways to overcome it."

That you may realize in some degree the difficulties that Mr. Blanding had faced, I quote from Kerl's Metallurgy a description of the operation in the well-known Plattner's Chlorinating Works at Richenstein. This chlorine solution of gold being obtained, the manipulation is as follows:

"The solution first warmed to 25°C., is treated with sulphuretted hydrogen, thus first neutralizing the chlorine, and afterward precipitating the gold."

"The precipitate is allowed to deposit; it is not completely deposited until the following day, when it is filtered.

"The clear liquid from the precipitation vessels is slowly conducted by glass syphons on to paper filters lying on perforated earthen dishes.

"The filtered liquid is led into sumpts to collect any sulphide of gold which may escape from the filters; the deposit in the vessel is washed and poured on the filters.

"320 filters are obtained from 16 days or 24 tons of ore;" (which is only one and a half tons per diem) "they are then dried and carbonized in four large pans, boiled with aqua-regia, washed, and the auric solution filtered into glass cylinders.

"Afterward the filters are again boiled in water, and the gold separated from the solution by sulphate of iron.

"The four precipitates are now collected on two filters, washed first with pure muriatic acid, and afterward with water.

"When eight such filters are collected, they are carbonized and the gold melted with borax and saltpetre."

The above details become truly formidable when carried out in extenso, and the bewildered operator becomes inextricably entangled in the multiplied decantations and filtrations, precipitations, now by one, and again by another agent, solution and re-solutions, washings and carbonizations, which surely accumulate, day by day, in the never-ending details of so complex a method.*

To still further entangle this complicated web, it was found, in our

* A ton of ore furnishes about 300 gallons of solution, including wash water; or a day's work in the Yadkin would require the above operations to be performed on 3,900 *gallons* of liquid. An idea may be thus formed of the labor and tedium attendant on such enlarged drudgery.

works, that the presence of copper interfered with the perfect precipitation of gold by sulphate of iron, even when great excess of the salt was used; the cement copper obtained from the solution after the gold had been precipitated was found to carry 30 cents of gold to the pound.

The ore operated upon yielded 22 pounds of cement copper to the ton; thus the loss in gold was $22 \times 30 = \$6.60$ per ton, which was fully 40 per cent. of the assay value of the ore.

A like interference of copper with the precipitation of gold is recited by Kerl (p. 614), in describing the chlorinating works at Schemnitz, he says:

"The liquid from the precipitated gold is collected and passed over iron, thus yielding some auriferous cement copper, the loss in gold being 18.21 per cent."

The shortcomings and difficulties of the older methods have been very briefly related, that you may realize the satisfaction with which the simple method of percolation through charcoal was welcomed, wherein, to the absolute certainty of securing the gold, was added the perfect separation from copper, and the obtaining the two metals in purity, and at a nominal expense of about 8 cents per ton.

This simple and effective remedy for the shortcomings of precipitation, removed the difficulties of working the most refractory ores of gold on an enlarged scale.

The charcoal filter will apply equally to all the processes of chlorination now known, and will necessarily apply to like processes, the discovery of which await further research and experiment, and which may in turn supercede the Plattner, Kiss, Paxter, Rozner, Mears, or Boynton processes of working gold ores by means of chlorine. It has been found that from one-half to one gallon of charcoal is sufficient for the solution from 1 ton of ore; while the absolute power of the carbon in dissociating gold from chlorine has not been absolutely determined, it has been experimentally proved that two ounces of charcoal will take a coating equal to eighteen and a half dwts., or $18.50, which carried out shows $148 to the pound, or $341,520 to a ton of charcoal.* The gilded grains exhibited on the screen much exceed this amount,

*In practice the operation is not carried to this extreme, because of possible disintegration of the surfaces and the settling of gold in metallic scales to the bottom of the vessel; and again, when a filter is heavily charged, the interest on the contained gold will exceed the cost of a fresh filter.

as they were taken from the surface of the filter, where the proportion of gold to the carbon was greater than the average of the whole contents, which yielded the above result.

It has been found in practice that the gold solution should be subject to the action of the carbon for about one hour, thus a filter containing 80 gallons of carbon may safely pass its own volume of the solution every hour, or the solution from one ton of ore in four hours. At this rate of running (unless the solution is heavily saturated with chlorine) there need be little fear of gold or chlorine escaping from the bottom spigot, but as a safeguard a second filter should be so placed that the upper one may discharge into it; this lower one is to be elevated to the place of the first when it is charged with gold.

In the process under consideration the presence of copper in moderate proportions becomes of advantage.

Whilst the gold to the uttermost particle is retained by the coal, the copper is not affected, and it passes onward in solution as chloride or sulphate, to its appropriate cistern where it is precipitated by scrap-iron, as metallic or cement copper.

Thus two per centum of copper as a by-product, will more than cover the cost of roasting and chlorinating the ore, or 40 pounds copper @ 12½ cents equals $5.00.

If there be silver in the ore, this metal will be converted into an insoluble chloride of silver in the chlorinator; in many ores the gold is alloyed with such proportions of silver that the coating of chloride of silver would protect the enclosed particle of gold from the action of the solvent, but in the revolving cylinder used in the Mears' system of chlorination, the moving sands scour off the curdy chloride of silver, and the chlorine acts with unimpeded energy, to the perfect solution of the gold.

Supposing then, that the ore is a chalcopyrite, carrying gold, silver, and copper sulphide, with ferric bi-sulphide, the elimination of the various elements would be as follows: In the preliminary roasting, the sulphides would be converted to ferric oxide and cuprous sulphate. As such it is subjected in mixture with due proportion of water in a revolving cylinder to the action of chlorine at a pressure equal to two atmospheres for one hour, more or less, according to the coarseness of the contained gold, after which the whole mixture is discharged into a filter arranged with sand and pieces of quartz to act as a leaching tank, from this the fluid contents; carrying the gold and copper, may

be drained and washed away by additional water, to pass through the carbon, where the gold will be intercepted, the copper passing over iron is deposited in metallic form.

Returning now to the washed sands in the leaching vat, we will find the insoluble chloride of silver; by treating these sands with a solution of hypo-sulphide of lime or soda (preferably the former), the silver will be dissolved, and by leaching, the silver solution will be carried to its appropriate tank to be precipitated as a sulphide, by hypo-sulphide of lime. Thus we secure a complete separation and obtain possession of the three metals, the two latter, viz., copper and silver, being by-products of the gold process.

The important question now arises as to the proportion of contained gold that may be obtained by this process.

EXPERIMENTS WITH CHARCOAL IN THE DEPOSITION OF GOLD.

The following details of experiments are given that the scientific reader may see that due precautions were taken to arrive at reliable results. The novelty of the appliances are offered as an apology for the minuteness of detail.

First Experiment.—A glass percolator, 18 inches deep, was filled with granulated pine wood charcoal, of sizes between a No. 16 and No. 40 sieve, a small gum tube and clamp at bottom served to regulate the flow; 3 quarts of coal were employed; and 100 gallons of solution, obtained from ore of the assay value of $15.65 per ton.

The solution represented 750 pounds of the above ore; it was so charged with chlorine that inhalation could not be made at the surface of the coal; temperature of the room, 75°F.; density of the liquid, 3.75° Beaumé. The rate of running was regulated to one gallon per hour.

At the expiration of every hour a sample was taken of the escaping liquid and tested for gold, with sulphate of iron; in each instance it failed to detect gold.

The color of the escaping liquid indicated the presence of copper; remembering that the presence of copper had hitherto impaired the action of sulphate of iron as a precipitant, it remained to be shown that the want of precipitate in the test tubes was a reliable indication of the absence of gold.

As a test, every tenth gallon of the filtrate was subjected to the following treatment:

The copper was precipitated with clean iron wire; the cement copper washed with water on a filter, then dissolved in diluted sulphuric acid and filtered on finest Swedish paper, dried, reduced to an ash, and assayed for gold; the resultant gold found in any single gallon weighed only .01 gr. Now, as one gallon represented $\frac{1}{200}$ of the solution from a charge of 1500 lbs. of ore, the above results shows a loss of but 2 grains, or $8\frac{2}{3}$ cents per ton of ore.

This result gave assurance that no appreciable gold was passing the filter.

The presence of chlorine was not to be detected in the escaping fluid.

The solution used in the experiment must have carried at least its volume in chlorine, or 13 cubic feet, equal 2·7 lbs. by weight. This disappearance of the chlorine attracted particular notice.

After the passage of the 100 gallons in 100 hour's time, running uninterruptedly, the carbon was washed, carefully incinerated in an open iron dish, and the resultant ash reduced with borax.

The button of gold weighed 139 grains, which being one-half a charge, is equal 278 grains per charge of 1,500 lbs., or

371 grains, at 4¼ cts. equal gold per ton	$15 77
Assay value of ore	15 65
Gold obtained above assay	$0 12

At first blush, it will be thought that more than the assay cannot be obtained. This is an erroneous opinion; a fire assay is but a smelting operation, in which lead particles are employed to wash out the fine atoms of gold diffused in a viscid glassy slag, whilst by solution, as in the case of chlorination, the finer determinations of chemical analyses are reached.

As bearing on this question, it is proper to state that in leaching the chlorinated sands, the washing with water is not continued to a perfect removal of the last traces of gold, as it would require a large volume of water to effect it. A careful supervision is kept by daily or hourly assays of the spent or waste sand, and a point is made that not over 60 cents per ton is allowed to escape. This remains a constant quantity whatsoever may be the value of the one operated upon.

The following results have been obtained on six experimental runs in the Chlorination Works at the Yadkin Mine, near Salisbury, N. C.:

No.	Tons Worked.	Assay per Ton.	Value of Ore.	Gold Mint Returns.	Compared with Assay.
1	17½	$11 90	$208 85	$216 33	+ 45 cts. per ton.
2	30½	11 90	362 95	383 34	+ 66 " "
3	9	25 20	226 80	237 99	+ $1 24 "
4	559	3 61	2,017 99	2,802 00	— 67 " "
5	265	5 04	1,335 60		
6	1,082	7 25	7,842 00	7,513 16	— 80¾ " "
	1,963	$6 11	$11,994 19	$11,152 82	— 43 cts.

COST OF THE PROCESS.

Labor and other charges on a single filter:

14 bushels charcoal, @ 5 cts	70
Grinding and screening, ½ day, @ 60 cts	30
1 boy, regulating flow, 4½ days, @ 25 cts	$1 12½
1 man, burning coal, 1 day, 60 cts	60
Reduction by crucible fluxes, etc	1 50
Equal 80 tons of ore at 5·3 cts. per ton	$4 22½

Briefly to recapitulate the advantages claimed for the carbon process, its peculiar features are:

First.—Great simplicity in all its details, and low cost in appliances, material and labor.

Second.—The complete *deposition* of gold from its solutions.

Third.—Its equal applicability *to all systems of chlorination* as applied to gold ores.

Fourth.—Greatly lessening the chances of loss through ignorance or carelessness of workmen.

Fifth.—The fineness or purity of the gold.

Sixth.—The securing of copper as a by-product at slightly increased cost.

NOTES ON THE PROCESS.

The mining and metallurgy of the precious metals form a lottery, in which the prizes bear an almost infinitesimal proportion to the blanks; in the search for gold this is pre-eminently the case. This arises from various causes:

First.—The minute proportion that gold bears to the ores in which it is held. The average of the ores that are worked carry less than $\frac{1}{45000}$ part gold.

Second.—Only a small proportion of the ores carry gold in an uncombined state (free gold) whilst the refractory pyritous ores offer increased obstruction, costs, waste, and uncertainty, which dishearten the miner and absorb his means.

Nature has so hedged and guarded her treasure-house as almost to justify the legends of the early miners, that kobolds, genii, demons, and elves, stood guard to scare all intruders. Apart from superstitious fears, it stands sure to-day, that nature exacts heavy toll and tribute from those who seek to share her treasure, and places the price so high, that gold will remain a precious metal, however abundantly it may occur.

In the alluvials and gravels of the valleys we meet the debris and sweepings of her treasure-house; in the brooks and rivers, the golden spoils of wasted rocks are offered to tempt us to seek whence they have come, for "Surely," says Job, "there is a vein for the silver, and a place for the gold, when they find it. As for the earth, out of it cometh bread, and under it is turned up as it were fire. The stones of it are the place of sapphires; and it hath dust of gold."

When the sources of rich supply are reached, and with toil and travail we penetrate to the deep deposits that lie stored in the embrace of the suffocating sulphur, or the poisonous arsenic, then unforeseen obstacles interpose, and malign influences oppose steady resistance to the most approved methods and appliances of scientific attainment.

So great have been these obstacles, and so high the cost imposed, that, to this time, man has yielded the point, and allowed the low grade pyritous ores to lie idle in their innumerable lodes.

The prodigal waste, and great cost of the methods in use, in working even the ores of free gold, are voluminously set forth and deplored in the writings of Overman, Raymond, Paul, Kerl, Küstel, Rittenger, and others, who have examined the subject. The recorded result of

their labors will sustain the statement that over thirty per cent. of the gold held in the ore is allowed to escape in the working.

The following figures extracted from official documents, show the percentage of gold lost at some of the most important mines in different parts of the world:

The losses at

The St. Juan del Rey Mine	@	30 per cent.
In the Brazils generally		35 "
In Piedmont		35 "
At Trell		35 to 40 "
In Hungary and the Tyrol		50 "
In Chili		66 "

Let us hope that such may not be the experience of the future, as it can be shown that the most refractory ores, in which at least $\frac{9}{10}$ of the gold of the world is locked, may be reduced at a cost, and with a closeness of saving which will in the end utilize the unmeasured stores of a kind, and grade of ore which has laid idle in ten thousand veins, and thereby add untold treasures to the resources of our country.

THE GREAT ICE AGE IN PENNSYLVANIA.

By Professor H. Carvill Lewis.

[Abstract of a Lecture delivered at the Franklin Institute, January 5, 1883.]

When Agassiz, over forty years ago, after a prolonged study of the Swiss glaciers, announced the conclusion that large portions of the continents of North America and Europe were once covered by an immense glacier, thousands of miles in extent, and several thousand feet in thickness, geologists the world over were startled at what then seemed a most improbable hypothesis. To-day there is hardly a truth in geology more widely accepted or capable of more conclusive proof.

It is here proposed to inquire into the nature of the facts which have led to such a conclusion, and especially to examine those facts in Pennsylvania, recently discovered, which prove the great glacier to have come within sixty miles of our own city.

The great "Northern Drift," as it has long been called by geologists, is a scattered deposit of stones and clay, which, unlike our stratified gravels and clays at Philadelphia, is a confused mixture irregularly dumped over the ground, thick in some places and thin in others, and

apparently unstratified by water. Large boulders are scattered through and upon this deposit, and upon close examination many of these boulders may be seen to be scratched longitudinally. They are of all sizes and shapes, generally rounded, yet often sharp. This deposit, often called *till* or *hardpan*, is not confined to the valleys and lowlands, but may be found covering the whole northern portion of our country, mountains as well as valleys, in an almost continuous mantle. Upon sharp mountain summits, and upon steep slopes, it is represented by the boulders and scratched stones alone; but on the other hand it may be as finely developed upon a high mountain plateau as at the level of the sea. The till has as much depth, and has just as characteristic features on the Alleghany plateau in Potter county, Pennsylvania, for example, at an elevation of over 2,500 feet, as it has at New York City at the level of the sea.

[A photograph was here thrown upon the screen, giving a section of *till* at one of the State quarries at Bangor, Northampton county, Pennsylvania. Large boulders lay imbedded in it at all angles.]

The boulders scattered in great numbers throughout the region covered by the Northern Drift can always be shown to have been transported from a more northern region. The lecturer had found boulders of syenite from the Adirondack mountains, and of granite from Canada of frequent occurrence in Pennsylvania. These are often perched upon mountain summits, and often are lifted from one valley and carried across a mountain range to the south into another valley. Thus the lecturer had found, in the valley immediately south of the Kittatinny mountain, immense boulders of Helderberg fossiliferous limestone which had been derived from outcrops in a valley north of the mountain, the boulders having traveled across the intervening mountain range, 1,500 feet high.

[A photograph was shown of a boulder of conglomerate perched upon the summit of Penobscot Knob, 2,220 feet high, the boulder having been transported from the next mountain on the north and carried across an intervening valley.]

These boulders, as well as the smaller stones imbedded in the till, are frequently scratched as though by some sharp instrument. The scratches on the stones are generally lengthwise, and form a characteristic feature of true till. Nowhere outside of the region covered by the Northern Drift, *except in the vicinity of glaciers*, do similar scratched stones occur.

[Numerous specimens of scratched stones from various parts of the State were exhibited, and a photograph of a large scratched boulder was shown.]

On exposed surfaces of rock, or where the till has been removed by any means, the rocks may be observed to be scratched, grooved, or polished as though by the movement of some solid heavy mass across it.

These grooves or striations are almost always in a southerly direction, and always correspond with the direction in which the accompanying boulders had been transported. The rocks underlying the till are ground off; all decomposed material having been rubbed off and removed by the agent which made the striæ and transported the boulders. No exposures of decomposed rock, such as may be seen anywhere in the vicinity of Philadelphia (at Gray's Ferry, for example), occur in the region of the great Northern Drift. The smooth, rounded surfaces of rock in that region are sometimes known as "*roches moutonnées*," from their resemblance to the rounded backs of sheep.

[A photograph of striated rock surfaces on Godfrey's ridge, near the Delaware Water Gap, were thrown upon the screen, and specimens exhibited.]

These three phenomena, then, the mantle of till, the transported and scratched boulders, and the smoothed or striated rock surfaces, are characteristic of the region covered by the "Northern Drift," and, with the high-level gravel banks and other phenomena more particularly to be described hereafter, are common throughout large portions of northwestern Europe and northeastern America. It was to satisfactorily explain these phenomenon that Agassiz's theory was proposed.

The early geologists supposed that this great Northern Drift was caused by an immense flood or deluge, the great mass of which swept furiously from the north toward the south, engulfing mountains and valleys alike, and carrying with it great masses of stones and rubbish, which, after the subsidence of the flood, remained as the deposits just described. It was found, however, that no satisfactory cause for such a flood or for such waves of translation could be found; nor could it be shown that water, however heavily laden with detritus, could either scratch the stones it bore, striate and groove rock surfaces, or form unstratified *till*. Nor could any flood transport great boulders across successive mountain ranges to positions often higher than the parent rock.

Another theory was therefore proposed. Great icebergs were supposed to have floated upon an inland sea, and to have both carried the boulders, and to have striated any rocks on which they might have grounded. On the other hand, the absence of any evidences of water

action throughout large regions covered by the till, the absence of any proof that icebergs can produce striæ, the difficulty of explaining the transportation of boulders from valleys to mountain tops, and especially the entire absence of any shore line for such an inland sea, militate strongly against any such theory. The southern edge of the "Northern Drift" beginning at the Atlantic ocean, and extending westward across the Alleghanies in a diagonal line, is anything but a shore line. This theory, however, known as the Iceberg Theory, is still supported by a few geologists, and will therefore be again referred to in our description of the glacial phenomena of Pennsylvania.

The glacial theory of Agassiz, on the other hand, somewhat modified by more recent discoveries, explains the observed facts and is based upon observations of phenomena produced at the present time. At the foot of many of the Swiss glaciers which have retreated from a former position, there may be seen polished and striated rock surfaces, transported and scratched boulders, drift deposits, and many other appearances precisely similar to those exhibited on a larger scale in northern Europe and America.

[The lecturer here described a personal examination of the termini of several Swiss glaciers, and especially of a valley between Meyringen and the Grimsel, where the polished rocks high up on either side showed the valley to be the deserted bed of a glacier.]

There are numerous proofs that the glaciers of Switzerland were formerly of enormously greater size than at present. There are boulders lying on the eastern flank of the Jura mountains which have been carried from Mt. Blanc upon the bosom of a great glacier 150 miles long, 50 miles broad, and 2,000 feet deep. An equally large stream of ice flowed southward from the same mountain far into Italy. A colder climate must have once prevailed to produce such a great extension of the glaciers.

In America also, both in the Rocky Mountains, and in the Sierra Nevada, there were formerly extensive glaciers, where now none, or only traces remain.*

Coming now to the great glacier of central Greenland, which with its extension northward to the Pole makes a true Polar ice-cap, it is most reasonable to suppose that the same refrigeration of climate which caused the local glaciers of Switzerland and of the Rocky and

* Similar evidences of the former greater extension of glaciers are found in many portions of the globe.

Sierra mountains to expand, caused similar great expansion of the Polar ice-cap.

A sea of ice, more than one thousand miles long, and thousands of feet in thickness, never traversed by human feet, now covers the whole interior of Greenland, mountains and valleys alike being buried beneath its mass.

[A description of this great *mer de glace*, as seen by Hayes, Nordenskjöld, and others, was here given.]

Streams of ice, issuing from this Greenland glacier often push far out to sea, where, by the buoyancy of the water, great icebergs are detached. These icebergs are often as much as half a mile in thickness, getting aground in water of that depth.

A sea of ice of even greater thickness covers the Antarctic continent, forming at its edge a wall of ice so high that one could not see over it from the top of a ship's masthead. Croll has estimated the thickness of the Antarctic glacier at its centre to be at least *twelve miles*.

Imagine now, these great polar ice-caps expanded in equal proportion with the local glaciers elsewhere, and the glacial theory is before us.

There is every proof that, ages ago, the climate being colder than now, the great Greenland glacier crept down so as to overspread the northeastern part of America and the northwestern part of Europe. Receiving accessions from such local centres of glaciation as Scandinavia, Scotland, and possibly Labrador, it probably also filled the bed of the Atlantic with ice far south of Greenland, the edge of the glacier reaching from Newfoundland to southern Ireland in a concave line. In its southward advance this great glacier scratched off rock surfaces, striated them in the direction of its motion, and scratched the fragments held in its grasp. Just as the ancient Swiss glacier carried boulders from Mont Blanc to the Juras, so this great continental glacier carried them from Canada across Lake Erie into Pennsylvania. Just as the Greenland glacier now fills the valleys and overtops the mountains, so this larger glacier advanced over mountain and valley alike, in a continuous sheet, to its final halting place, only sixty miles north of Philadelphia.

It is probable that future research will show a similar great ice-sheet to have advanced northward from the Antarctic continent.

This great northern glacier, reaching in America from Greenland to St. Louis, and from Alaska to New Jersey, was so thick as to overtop

Mt. Washington, dropping transported boulders upon its summit. Even at its very edge, as observed in Pennsylvania, the glacier was at least 800 feet thick. A hundred miles back from its edge, among the Catskills, it was at least 3,100 feet thick, while two hundred miles farther, in northern New England it was 5,000 feet thick. In northern Canada it must have been still thicker.

The thickness of the glacier is known by the height to which transported boulders and striated rock surfaces may be found. Thus in Pennsylvania, the lecturer has found that Pocono Knob, 2,175 feet high, juts into the extreme edge of the glacier, having however no marks of glaciation, and therefore showing the edge of the ice not to have been deep enough to ride over it, while, on the other hand, Penobscot Knob, 2,250 feet high, only eight miles back from the southern edge of the glacier, was overridden by it, exhibiting striations and transported boulders upon its very summit.

It was this glacier which formed the till, which dumped down irregularly the various unstratified deposits so characteristic of the drift-curved region, and which both abraded the rock surfaces and transported and rounded the fragments which it tore off in its passage.

The exact extent of this great glacier is not accurately known in all portions, but is now being studied. In general, it appears that its southern edge extended from Alaska in a southwest direction to the northwest corner of Dakota, whence it passed through the centre of Nebraska and the northeastern corner of Kansas, continuing eastward through the centre of Missouri to the Mississippi river near St. Louis. It then passed along the southern edges of Illinois and Indiana, entering Ohio at Cincinnati, then trending northwest to the Pennsylvania line a few miles north of Beaver. In Pennsylvania, as will presently be stated more in detail, it passed northwest from Beaver county to Warren county, where it entered New York. Making a sharp curve in Cattaraugus county, New York, it again entered Pennsylvania in Potter county, and passed southeast to Belvidere in Northampton county, where it crossed into New Jersey. Passing in a southeast direction across New Jersey to Staten Island, it again entered New York, and traversing the whole length of Long Island finally goes out to sea, appearing on Block Island, Cape Cod, and at a few other detached points. The edge of the glacier probably corresponded with St. George's bank and Sable Island shoal outside of Nova Scotia, and, passing southeast of Newfoundland and south of Greenland,

probably crossed the Northern Atlantic and again passed southward outside of the Irish coast, so as to enter the southwest corner of England. It appears to have crossed England in a westerly direction so as to pass not far from London, and then, crossing the North Sea, to have traversed southern Holland, northern Austria, Saxony, passing near Dresden, until entering Poland, south of Warsaw, it finally curved northeast in Russia, passing east of Moscow, and entering the Arctic Ocean just west of the Ural mountains.

[A map of the world was exhibited, showing the approximate limit of glaciation.]

The glacial stream was reinforced by glaciers from the mountains of Scotland and Scandinavia, and these local glaciers have been proved to have remained and to have formed striæ long after the continuous ice-sheet had departed. There are many evidences of a second glaciation of more limited size and of local origin.

That the phenomena of this great drift-covered region are due to the actual presence of a great glacier, rather than to any open sea, bearing icebergs, should be forever settled by the discovery of one crucial fact, the presence of a *terminal moraine*. A true glacier pushes up at its foot a mound of unstratified material, composed of angular, rounded, and striated fragments of rock, which the ice has taken up at various points along its course and carried to its terminus to form a moraine. On the other hand any body of water is bounded by a level shore line composed in great part of water-worn pebbles.

By the discovery in Pennsylvania and in other portions of America of a true terminal moraine, which, as a continuous wall of unstratified and glaciated material, crosses over mountain and valley alike, regardless of topography, everywhere forming the boundary between the glaciated and the non-glaciated region, the glacial theory has recently been remarkably confirmed.

[Professor Lewis here described the investigations in New Jersey, and along Long Island and southern Massachusetts, which first demonstrated the existence of a true terminal moraine, and referred to the discovery of similar moraines in Wisconsin and Minnesota, which marked halting places in the retreat of the glacier. He stated that the "coteaus" of the northwestern prairies have been shown to be parts of such moraines.]

Convinced from personal observations as well as from the considerations just mentioned, that it was possible to trace a terminal moraine across Pennsylvania, the lecturer, having obtained the aid of the Geological Survey of Pennsylvania, and having, through part of the

exploration, the able assistance of Prof. G. F. Wright, had been able to follow and define the southern limit of glaciation for the first time in a continuous line four hundred miles in length across our State, and to find that it is everywhere marked by a remarkable accumulation of glaciated material, which, forming a great terminal moraine, winds across mountains and valleys, across deep ravines and high mountain ridges, from the lowlands of the Delaware to the great Alleghany plateau, is continuous from end to end, and forms a feature of great interest in studies upon the glaciation of this country.

The method employed in discovering the line of the moraine was to zigzag along its course from the glaciated into the non-glaciated region, and *vice versa*, going each time far enough on the one side to be fully satisfied of the absence of glaciation, and on the other to find undoubted traces of its action.

The distinction between the glaciated portion of Pennsylvania and that region south of glacial action is very marked. Although the general topography of the two regions is alike, the varied superficial features due to glacial agencies, the far traveled and scratched boulders, the smoothed and striated rock exposures, the unstratified deposit of impure clay, which, filled irregularly with both round and sharp stones, has been called *till*, the long *hummocky* ridges of stratified sand and gravel known as *Kames*, and especially the numerous glacier-scratched fragments and pebbles, all these deposits are in strong contrast with those south of the glacial action, where all the gravels are stratified and the pebbles water-worn, where the rocks are never polished or striated, but, on the other hand, often decomposed to a great depth and where, except near the sea coast, wide stretches of the more elevated regions are perfectly free from all drift.

The line separating the glaciated from the non-glaciated region is especially defined by a remarkable accumulation of unstratified drift material and boulders, which, heaped up into irregular hills and hollows over a strip of ground nearly a mile in width, forms a continuous line of drift hills more or less marked, extending completely across the State. These hills vary in height from a few feet up to 100 to 200 feet, and while in some places marked merely by an unusual collection of large transported boulders, at other places rise as immense accumulations to form a noteworthy feature of the landscape. When typically developed, this accumulation is characterized by peculiar contours of its own. A series of *hummocks* or low conical hills, alternate

with short straight ridges, and enclose shallow basin-shaped depressions, which like inverted *hummocks* in shape, are known as *kettle holes*. Large boulders are scattered over the surface, and the unstratified *till* which composes the deposit is filled with glacier scratched boulders and fragments of all sizes and shapes. The average width of the moraine is about one mile.

The two facts which are of especial importance in relation to this line of drift hills are, (1.) That, as shown by the absence of stratification, by the angularity and the striated surfaces of its enclosed stones, and by its topograpical position, it has rarely been subjected to the action of water; (2.) That, as proved by numerous glacial striæ and by transported boulders, its course is always at right angles to the direction of glacial movement.

These facts, with others about to be given in detail, led the speaker to regard this accumulation as a true *terminal moraine*, marking the southern extension of the great ice-sheet of northeastern America. Like the moraine at the foot of the Rhone glacier, which, as recently observed by Chamberlin, forms diminutive hummocks and kettle holes, and has on a small scale the same characters and topography as the great moraines of Wisconsin, this great Pennsylvania moraine appears to have been pushed out at the foot of the great glacier of the ice age.

The general course of this moraine across our State is as follows (see accompanying map): Appearing first in Northampton county, a mile below Belvidere, at latitude 40° 49′, it appears through the stratified drift as low gravel hills, which, winding up over the slate hills to the west, are soon developed into an accumulation of typical till, holding kettle holes and filled with boulders. Winding in a great curve first westward and then northward, it reaches the base of the Kittatinny mountain three miles east of the Wind Gap.

Ascending to the top of the Kittatinny mountain, 1600 feet high, the moraine crosses over it, being well shown upon the very summit, and entering Monroe county, crosses the great valley between the Kittatinny and the Pocono, enclosing in its course several moraine lakes. Having crossed this valley, and reached the base of the Pocono escarpment, it swings sharply back and around Pocono Knob, immediately afterwards to ascend the steep face of the mountain to the wide plateau on top, 2100 feet above the sea. Crossing this in a majestic curve, heaped up in an immense accumulation, it goes first north and afterwards west, until it reaches the Carbon county line.

Crossing the centre of Kidder township, Carbon county, it reaches the gorge of the Lehigh river, some ten miles north of Mauch Chunk. It crosses the gorge at Hickory run, and, without swerving from its general northwestern course, ascends mountain range after mountain range in Luzerne county, descends to the valley of the east branch of the Susquehanna, and crosses the river at Beach Haven, here forming immense heaps of drift, afterwards to be washed down the river into terraces.

Then, in Columbia county, following along the base of Huntington or Knob mountain for awhile, it finally ascends it, and crossing over the summit at a height of 1500 feet above the Susquehanna just below, descends the north slope of the mountain to the broad undulating valley to the north. Taking a northerly course, it follows up on the east bank of Fishing creek to the north or Alleghany mountain. The summit of the Alleghanies in Sullivan county is covered with glacial striæ, and contains boulders and other marks of glaciation. The moraine entering Lycoming county, passes westward along the base of the mountain, crossing in its course the Muncy and Loyalsock creeks, and finally, near the village of Loyalsock, turns at right angles and ascends the mountain.

Having reached the summit of the Alleghenies, over 2000 feet above the sea, it crosses the picturesque canon of Lycoming creek, and passing west through a wild, wooded region nearly as far as Pine creek, it begins a nearly straight northwestward course, through the southwest corner of Tioga county, and the northwest part of Potter. In the high ground of Potter county, the moraine crosses a great continental watershed, from which the waters flow into the Gulf of Mexico, Lake Ontario, and Chesapeake bay. The moraine is here finely shown at an elevation of 2580 feet, being higher than elsewhere in the United States.

The line of the moraine now enters the State of New York, in the southwest corner of Allegheny county. Passing still northwest and entering Cattaraugus county, it twice crosses the winding course of the Allegheny river, east and west of Olean, then, trending to a point five miles north of Salamanca, in latitude 42° 15′, it forms a remarkable apex, from whence to the Ohio line its course is southwest. Turning at right angles to its former course, the moraine passes southwest through the southeast corner of Chautauqua county, and keeping approximately parallel to the course of the Allegheny river, re-enters

Pennsylvania, in Pine Grove township, Warren county. It crosses the Conewango river seven miles north of Warren, forming immense accumulations in the valley of the river.

Then trending west in Warren county, still at a general elevation of nearly 2000 feet above the sea, it crosses one gorge after another, and forms a line separating, not only the glaciated from the non-glaciated region, but also the cultivated from the uncultivated and densely wooded region.

In Crawford county, the line appears in the southeast corner, and crosses Oil creek between four and five miles northwest of Titusville.

In Venango county it skirts the northwest and west boundary of the county, crossing French creek four miles west of Franklin.

It crosses the three northwest townships of Butler county, and the southeast corner of Lawrence. The Beaver river is crossed by the moraine eight miles south of New Castle.

The moraine traverses the extreme northwest corner of Beaver county, and, in the middle of Darlington township, thirteen miles north of the Ohio river, and at a latitude of 40° 50′, crosses the Ohio State line.

The moraine thus leaves Pennsylvania at precisely the latitude at which it entered the State, and if a straight line were drawn across the State between these two points, the line of the moraine would form with it a right angled triangle, whose apex was 100 miles distant perpendicularly from its base. The total length of the moraine, as here shown, is about 400 miles. The moraine crosses the Delaware at an elevation of 250 feet, the Allegheny at an elevation of 1425 feet, and the Beaver at an elevation of 800 feet above the sea, or 225 feet above Lake Erie. Upon the high lands it rises higher by 1000 feet or more.

Coming now to the details of the moraine, it will be impossible in the brief space of a lecture to mention more than a very few of the many interesting phenomena noticed all along its course. The details in full will be found in forthcoming Report Z. of the Geological Survey of the State. The beautiful photographs thrown upon the screen were made by Mr. E. H. Harden, of the Geological Survey, and are the first ever taken or exhibited of the Great Terminal Moraine in any part of the world.

[Photographs were exhibited of the moraine, near Bangor, Northampton county; details of the same; moraine near Saylorsburg, Monroe county; "kettle-holes" in the same; moraine on summit of Pocono mountain; moraine forming dam on Fishing creek, Columbia county, etc.]

In *Northampton* county, the moraine is very finely developed west of Bangor, where it forms a series of "hummocky" hills, which, 100 to 200 feet in height, and covered with transported and striated boulders, rise abruptly out of a clayey plain to the west. Glacial striæ upon exposed surfaces near Bangor point southwest, or towards the moraine. After following the moraine to the base of the Kittatinny mountain, it became of great interest to know whether a great lobe of ice descended from New Jersey along the lower side of the mountain, or whether a tongue projected through the Delaware Water Gap, or whether the glacier even so close to its southern limit, came bodily over the top of the mountain, unchecked by it, and unchanged in its course. The last, the most improbable of these hypotheses, and certainly the least expected by the speaker, proved to be undoubtedly the true one. The speaker had been able to show that the moraine crossed mountain near Offset Knob, that large boulders, derived from lower elevations several miles northward, lie perched all along the summit, 1400 feet above the sea, and that, as shown by the numerous striæ on the northern slope of the mountain, running *up-hill*, the glacier moved diagonally up and across the mountain, uninfluenced in any way by the presence of the Water Gap, and finally came to an end in the valley south of the mountain, as marked out by the terminal moraine. Huge boulders of fossiliferous limestone, sometimes 30 feet long, were torn by the ice from their parent strata in Monroe county, on the north side of the mountain, lifted up a thousand feet, carried across the mountain, and dropped finally in the slate valley of Northampton county. The lecturer had found one of these limestone boulders upon the very summit of the mountain, where the jagged sandstone rocks had combed it out of the ice during its passage across. The journeys of these boulders were short, but that of a well-rounded boulder of Adirondack syenite, which the lecturer had found in the same county, was about 200 miles.

In *Monroe* county, the course of the moraine as it winds from the top of the Kittatinny mountain down to Cherry Valley and then up again on to the Pocono, is a complete vindication of the glacial hypothesis. It is in no sense a water level, nor could it have been formed by floating ice. No other cause than that of a great glacier could form a continuous accumulation of glaciated material, which contains no evidences of water action and which follows such a course. The fact discovered that no tongues of ice were protruded either through the

Delaware Water Gap or down the broad valley between the Pocono and Kittatinny mountains, indicates the immense size of the glacier. Although more than 1000 feet lower than the mountains and 12 miles in width, the valley last mentioned deflected the southern boundary of the ice but a few miles.

[There are no striæ indicating passage of ice through the Water Gap, the supposed striæ being due to water action.]

Again, neither on the mountains nor in the valley does the moraine rest against any defined barrier as would be the case were it a shore-line.

The moraine is wonderfully shown upon the summit of Pocono mountain, over 2000 feet above the sea, where a great ridge of moraine hills twelve miles long, one mile wide, and 100 feet or more high, composed of unstratified till, and bearing numerous boulders of Adirondack gneisses and granites, rises out of the level, sandy plain of the Pocono plateau and sweeps around from Pocono Knob into Carbon county. Known locally as "Long Ridge," its origin has never before been suspected. It encloses remarkable little "moraine lakes" without inlet or outlet, and is heaped up into just such conical hills as may be seen in the moraine in Southern Massachusetts. Nothing can more clearly show the continuity and uniformity of action of the great glacier than the identity of its moraine accumulations at such remote points.

[The lecturer here described some of the *striæ* of Monroe county, exhibiting photographs. One photograph represents *cross striæ* seen south of Stroudsburg. A second movement of the glacier down hill, after it had become smaller, had crossed the striæ made by a more general movement of the ice. He said that the direction of ice movement could often be told from the cuneiform shape of the striæ.]

The "*Kames*" of Cherry Valley, fine examples of which appear south of Stroudsburg, are interesting relics of sub-glacial water action. They are composed of stratified water-worn gravel, having often an anticlinal structure, and, as a series of conical hills and reticulated ridges, enclosing "kettle holes," form conspicuous objects in the centre of the valley. They appear to have been formed by sub-glacial rivers, which flowing from the moraine *backwards*, under or at the edge of the ice, emptied into the Delaware Valley. A study of the great sub-glacial drainage, of which kames are the most prominent relics, throws much light upon certain high-level stratified gravels whose origin has been ascribed to great changes of elevation.

[Photographs of *Kames* in Cherry Valley were exhibited. The lecturer then described the *terraces* near Stroudsburg, and referred to the Indian name of that region, Minisink, meaning "the waters have gone," as an indication of the legendary memory of the flood following the retreat of the glacier. He exhibited a photograph of a glacial groove which he had discovered on the Kittatinny mountain near the Water Gap, which, six feet wide and seventy feet long, had been gouged out by some great rock imbedded in the moving glacier.]

Immense as was the power of the slowly moving glacier, it had but slight effect upon the topography of the country. It is a mistake to suppose that glaciers can level down mountains or scoop out cañons. The glacier has merely "sandpapered" the surface of the rocks. The glacier passed bodily across the sharp edge of the Kittatiny mountain without having any appreciable effect upon it, the glaciated part of the ridge being as high and as sharp as that part south of the moraine.

In *Carbon* county, the moraine passes across the wild wooded region in the most northern township of the county, enclosing several moraine lakes in its course and crossing the Lehigh near Hickory run. These moraine lakes are kettle-holes holding water, while other lakes, such as Long Pond on the Pocono plateau, are due to the damming up of their outlets by the moraine. An abundance of lakes is characteristic of a glaciated region, being generally due to the obstruction of streams by the unequal distribution of the till.

The point where the moraine crosses the Lehigh may be distinctly seen by any one traveling upon either the Lehigh Valley Railroad or the Lehigh and Susquehanna Railroad, the contrast between the glaciated and the non-glaciated regions being sharply defined. South of the moraine, the rocks bordering the picturesque gorge of the Lehigh are bare or covered with frost-broken fragments, while the products of aerial erosion known as "Pulpit Rocks" may be seen. The gorges formed by tributary streams are rocky and free from gravel. On the other hand, in the glaciated portion of the valley, a covering of gravel and rounded boulders appears on either side, and the drift has filled up the gorges occupied by tributary streams, often transforming them into shallow valleys, while terraces and ridges of gravel appear in the river valley itself. Just above White Haven, glacial striæ upon the rocks may be seen from the car windows.

The general movement of the ice throughout this region, as shown by the striæ upon the summit of Penobscot Knob, 2200 feet high, is south 10° west. This is precisely at right angles to the course of the

moraine. The latter traverses the southern part of *Luzerne* county in a direction north of west, crossing in its course numerous mountain chains, by each of which it is locally deflected northward.

[The lecturer here described some of the glacial phenomena of Luzerne county. He stated that at the point where the terminal moraine crosses Buck mountain, in a line diagonally across the mountain, the moraine is so sharply defined that he was able to stand with one foot upon the glaciated and the other upon the non-glaciated region. He described the fine kames between Scranton and Pittston, on the Lackawanna river, and showed that they were nearly parallel to the glacial striæ.

He then gave some details of the course of the moraine as traced through *Columbia* county. He stated that it was interesting to find that in *front* of a mountain chain, such as Huntington mountain or the Alleghany mountain, the moraine was poorly developed, as though the mountain had *combed out* the drift from the ice. Speaking of certain gravel deposits south of the moraine, due to floating ice, he said that the best test of a glaciated region is the striation of its pebbles.

He described an instructive portion of the moraine, where, 3½ miles northwest of Berwick, it seems to abut against a high slate hill, which furnishes, therefore, a *section* of the end of the glacier. It shows that the extreme edge of the ice was about 400 feet thick, and that while the moraine and the scratched pebbles were carried along at the base of the ice, sharp fragments of sandstone were carried on top.

The interesting course of the moraine along the eastern bank of Fishing creek was described, where the glacier stopped abruptly on the downward slope of a hill, stopping simply because its inertia became exhausted. A photograph of the moraine where it crossed the creek, forming a great dam, was exhibited, and it was shown that the moraine was often steeper at the back than at its front edge—a fact analogous with the features of modern Swiss moraines.

The evidences of glaciation upon the Alleghany mountain in Sullivan county were given, the striæ pointing south 9° west, and the moraine was followed along the base of the mountain to a point in *Lycoming* county near Loyalsock, where it climbed up to the great Alleghany plateau, and then, keeping at a high elevation, passed through Tioga and Potter counties into New York.]

That this great region of high elevation (over 2500 feet) had a decided influence upon the general course of the moraine is inferred from the local influence already shown by the lecturer to have been exerted by single mountain chains, and it is probable that as the lowlands along the Atlantic allowed the ice to flow as far south as Belvidere, so this great mountain region, acting like a wedge, caused the moraine to swing northward into New York; and so, too, the depressions of Lake Erie and the Mississippi Valley produced another and more

extended southward flow, a portion of which traversed the western part of our State.

[Professor Lewis here described the remarkable apex made by the moraine north of Salamanca, N. Y. He showed that it was probable that the Allegheny river flowed under a tongue of the glacier, 10 miles broad and 2 miles long, through a sub-glacial channel at the time of its greatest extension near Olean. He described a great natural dam across the valley of Great Valley creek, near Peth, where the moraine stretches across the valley from side to side, and he spoke of the contrast between the numerous drainage valleys which drained the waters of the melting ice into the Alleghany river, and those valleys which took their rise south of the moraine and were free from all drift.

After giving some details of the western lobe of the ice sheet in Pennsylvania, he spoke of some curious deposits of glaciated material which occurred in a narrow strip of ground immediately in front of the moraine, and which he had named the *fringe*. These deposits consisted of boulders of Canadian granite, and other rocks, which he found perched upon the summits of hills, sometimes as far as five miles in front of the moraine, though never farther. This glacial "fringe," confined to the western part of the State, was found to increase in width from two miles in Warren county, to five miles on the Ohio line, and was at first a puzzling phenomenon. The hypothesis proposed was that, like breakers on the seashore, the top of the ice overreached the lowest strata by the width of the "fringe," and that while the moraine marked the halting place of the bottom of the ice, by which it was formed, the far-transported boulders were carried on more rapidly in the top strata of the ice, and were dropped outside of the moraine to form the "fringe." Other facts observed in the western part of the State were given, and specimens of Canadian boulders were exhibited. It was stated that the striæ in the western part of the State all pointed southeast, being at right angles to those in the eastern part of the State, but like them, pointing always towards the moraine.]

Having thus reviewed briefly some of the more important glacial phenomena of our State, it remains to inquire into the probable *cause* of the great glacier, into the origin of the cold that allowed the polar ice-cap to creep down as far as the great terminal moraine, and finally into the probable *age* of the glacial epoch.

Among the various causes assigned, by different writers, for the glacial epoch, the following may be enumerated:

1. Changes in the obliquity of the ecliptic.
2. Changes in the position of the earth's axis of rotation.
3. The precession of the equinoxes, combined with a greater eccentricity of the earth's orbit.
4. Variations in the amount of heat given off by the sun.
5. Differences in the temperature of portions of space passed through by the earth.

6. Differences in the distribution of land and water, and differences in the elevation of certain portions of the earth.
7. Differences in the flow of oceanic currents, and a change of direction of the gulf stream.
8. Changes in the earth's atmosphere, in its capacity for allowing the radiation of heat, in its power of absorbing moisture, in its density and height, in its temperature, and in the height to which clouds can rise in polar regions.

Still other causes, such as the gradual cooling of the earth from a state of incandescence, have been assigned.

The most probable of these theories are the third and sixth of the above list.

[Professor Lewis here explained the astronomical changes which would cause the winters to be longer than the summers, thus preventing the melting of the accumulating snow. He showed that owing to the elliptical form of the earth's orbit we are about 3,000,000 miles nearer the sun in the winter than in the summer of the northern hemisphere, but that 10,500 years ago this condition of things was reversed, and that we were nearer the sun in summer. He showed also that whereas the sun is now nearly in the centre of the earth's orbit, about 100,000 years ago the eccentricity of our orbit was much greater, the pole then being 8,000,000 miles nearer the sun in winter than in summer. He thought, however, that terrestrial causes were much more potent in causing the glacial epoch than any astronomical changes. There is reason for believing that in glacial times, the land in Labrador and Greenland was elevated at least 600 feet higher than at present, and that at the same time the warm oceanic currents were withdrawn. The glacier grew in the neighborhood of the Atlantic and Hudson's Bay, where moisture was abundant, and did not reach into the dry interiors of either America or Asia. He explained Croll's molecular theory of the motion of the ice, and suggested the possibility of a glacier flowing towards an origin of heat without the aid of gravity.]

Finally, it becomes of interest to inquire into the length of the glacial epoch, and to estimate, if possible, the time that has elapsed since the glacier retreated from Pennsylvania to its present home in Greenland. Astronomical data teach that the cold period began 240,000 years ago. Now, just as every year the greatest cold of our winter does not occur at the time of the shortest day, but fully six weeks later, so it is evident that the greatest cold of the glacial epoch did not occur till many thousands of years after the date mentioned. Again, the great eccentricity of our orbit ended 80,000 years ago, but just as our winter snows remain long into the spring, so the great glacier remained long after its immediate cause had been withdrawn. The larger the mass of ice, the longer it would take to melt. There are

data which lead us to believe that the glacier did not finally withdraw from the United States until as recently as 10,000 to 15,000 years ago. We are here on delicate ground, for geological time is relative rather than absolute, and it is not safe to fix dates. Even in history, all dates back of the time of Abraham are most uncertain.

Special interest, however, attaches to speculations regarding the time of the close of the glacial epoch, since it has been shown to be closely connected with the antiquity of the human race. Stone implements, made by man, have been discovered on both continents in gravels deposited at the close of the glacial epoch. They have been found under conditions that leave no doubt that man, in a rude state, with habits resembling those of the Esquimaux, lived at the time when the river valleys were flooded with water from the melting glacier. That man existed before the glacial epoch, has been inferred from certain facts, but not satisfactorily proven. The speaker has made careful search in glacial deposits all along the line of the moraine for traces of man, without success; while, on the other hand, in the post-glacial gravels of the Delaware, as will be shown in the next lecture, human implements have been found in abundance by Dr. Abbott.

So important, therefore, does the time of the final melting of the glacier become, that we are tempted to inquire still further, even at the risk of too greatly prolonging this lecture, and to gather what facts we can to bear on our subject.

It is a question which geological data alone are insufficient to solve. The only clew, and that a most unsatisfactory one, is afforded by calculations based upon the amount of erosion. This, like all geological considerations, is relative rather than absolute, yet several calculations have been made, which, based either upon the rate of erosion of river channels, or the rate of accumulation of sediment, have attempted to fix the date of the close of the glacial epoch.

When a student of surface geology, who has lived south of glacial action, examines for the first time the true glacial drift and sees the kame-like ridges and bowl-shaped depressions maintaining regular outlines and steep slopes, he cannot but be struck with the comparatively recent look of these deposits. He cannot but believe that if the great periods of time have elapsed since their depositions, which some geologists maintain, the gravel ridges would be rounded down and the kettle-holes filled up by the erosive action of frost, rain and wind. Recent investigations in glacial geology are bringing forward many

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THE GREAT TERMINAL MORAINE ACROSS PENNSYLVA

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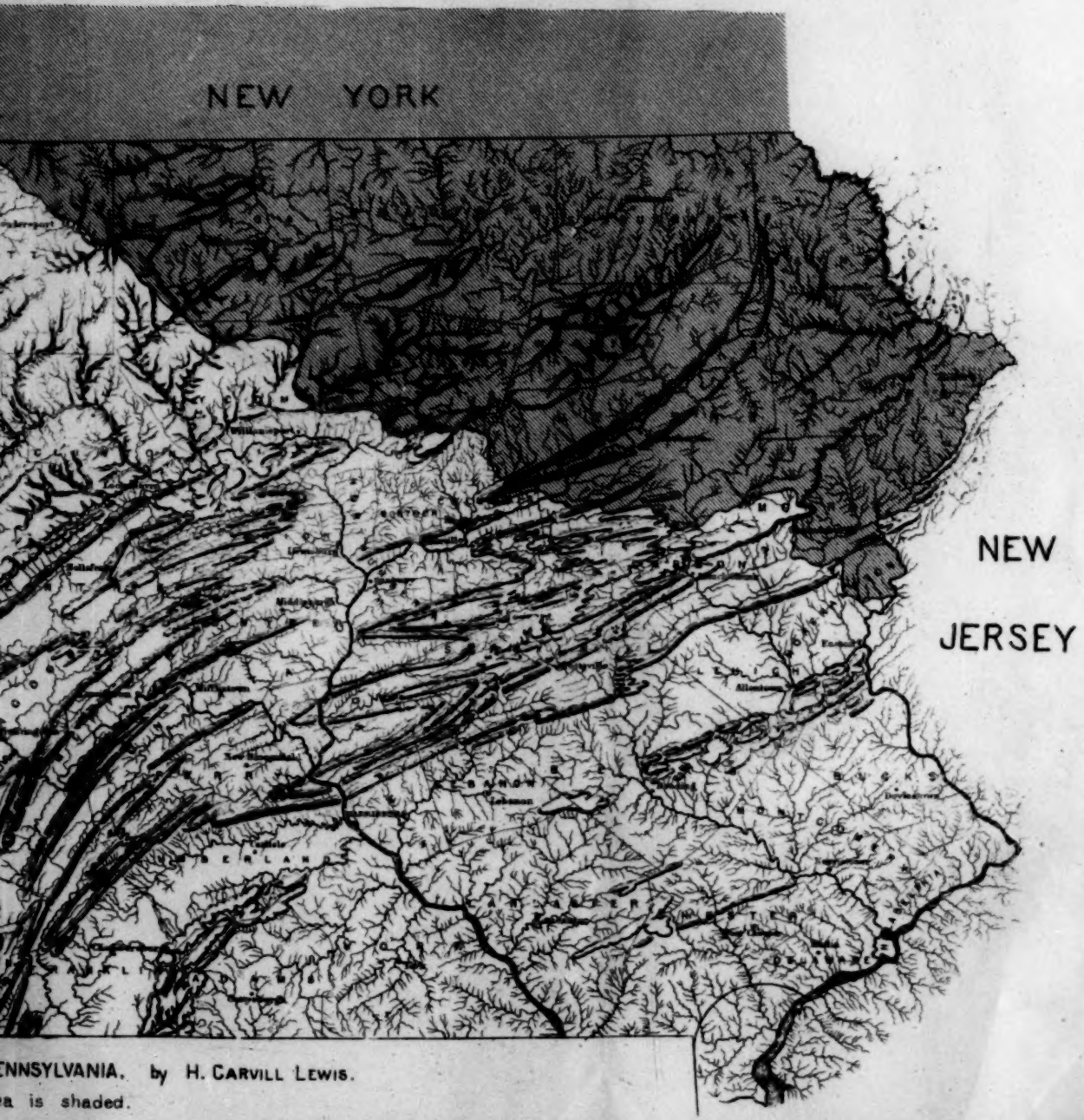


NNSYLVANIA. by H. CARVILL LEWIS.
a is shaded.

evidences that the final disappearance of the glacier in eastern America was not far remote.

Prof. Chamberlin's statement, that "no sensible denudation has taken place in Wisconsin since the glacial times in either drift bearing or driftless areas;" Mr. Upham's remark, when speaking of the lakes which dot the surface of Minnesota, that "the lapse of time since the ice age has been insufficient for rains and streams to fill these basins with sediment, or to cut outlets low enough to drain them; though in many instances we can see such changes slowly going forward;" and Dr. Dawson's observation that "In Canada, the character of the river-courses cut through the glacial beds, and their very unformed and imperfect excavation would lead to the belief that only a few thousands of years have elapsed since the glacial beds were laid down;" these, with similar observations by the lecturer, all agree with conclusions drawn from the good preservation of shells and bones in terrace deposits, and the fact that in zoology since the glacial age no geological changes even leading to the production of varieties have occurred, in bringing the close of the glacial age into our own epoch.

Prof. Wright finds from a study of a glacial "kettle hole" in Massachusetts, that the accumulation of peaty matter in it, whether caused by growth of vegetation or by winds and rains, is equal to a level deposit of eight feet in thickness. At the rate of one inch in a century, which is probably less than the true rate, this would place the close of the glacial epoch at less than ten thousand years ago.

A still more recent estimate has been made by Dr. Andrews, who, from calculations based upon the erosive action of the great lakes, concludes that the total lake deposits made since the glacial epoch, were formed within seventy-five hundred years.

Another source of calculation is the recession of the falls of a river since glacial times. The most notable calculation of this kind is that made upon the recession of the Falls of Niagara. A gorge seven miles in length has been cut from Lewiston to the present falls. Beds containing recent shells and mastodon teeth occur in the banks above the gorge, at the whirlpool, three miles below the falls, and also on Goat Island above the falls, indicating that the waters of Lake Erie once extended up over the gorge and present falls, and that since that period a large portion of the gorge had been excavated. At the whirlpool is an ancient pre-glacial channel, which, having been filled

with drift in glacial times, forced the river to cut a new channel through the rock since that period.

There are here, therefore, data for calculating the close of the glacial epoch. If the whole gorge has been cut out since that epoch, at the rate of one foot per year, thirty-five thousand years would be required. It has been, however, more than once suggested that a portion of the gorge is pre-glacial. Prof. Dana supposed about one mile of it to be pre-glacial, but Mr. Belt, after a personal investigation, concludes that the gorge above the whirlpool was excavated nearly up to the present position of the falls in pre-glacial times. After giving the evidences upon which he founds his opinion, he says: "If the conclusion at which I have arrived is correct, that the gorge from the whirlpool to the falls is pre-glacial, and that the present river has only cut through the softer beds between Queenstown and the whirlpool, and above the latter point merely cleared out the pre-glacial gorge in the harder rocks, twenty thousand years or even less is amply sufficient for the work done, and the occurrence of the glacial epoch, as so measured, will be brought within the shorter period that, from other considerations I have argued, has elapsed since it was at its height."

A calculation of a similar kind has been made by Prof. Winchell, upon the recession of the falls of St. Anthony, since the last glacial epoch. These falls, in the Mississippi river, were discovered in 1680, and a continuous record of their recession may be found since then. A narrow gorge, formed by their recession, extends from the falls to Fort Snelling, eight miles south. Below this point the valley widens, and shows evidence of having been excavated in pre-glacial times. From the falls to Fort Snelling, however, the drift, which lies above the rocky walls of the gorge, has been cut through so as to form a bluff on either side; a fact, showing the post-glacial age of this gorge. An ancient channel of the river, now filled with glacial drift, is described and the evidence seems decisive that, since the glacial epoch, the river, having been forced out of its old channel, has cut out a new one eight miles long, through the rock. Unlike the rocks at Niagara, those at the falls of St. Anthony are horizontal and of unvarying composition, and any conclusions made here will be of much greater accuracy. Prof. Winchell gives three separate measurements, which result in the following terms of years required for the total recession, viz.:—12,103 years; 6,276 years; and 8,202 years. He holds that

an average of these rates—8,860 years—represents the time which has elapsed since the maximum cold of the last glacial epoch.

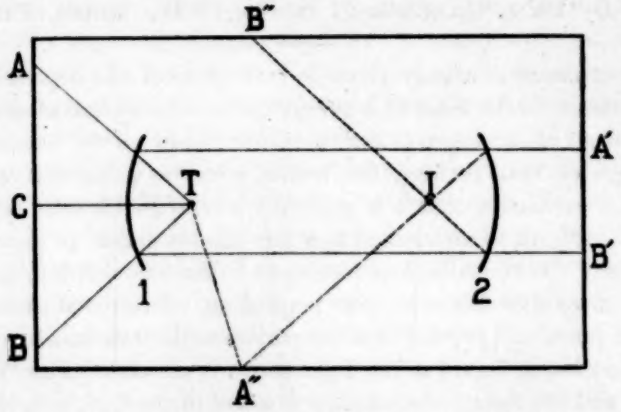
Thus we find, that if any reliance is to be placed upon such calculations, the time of the melting of the glacier need not be longer back than from 10,000 to 15,000 years ago. The conditions at that time will be treated of in our next lecture. It may be that as investigations are carried further, they will result not so much in proving man of very great antiquity, as in showing how much more recent than usually supposed was the final disappearance of the glacier. Here, however, we are entering a field where many sciences meet and where each must help the other.

APPARENT RADIATION AND REFLECTION OF COLD.

By Prof. Charles. F. Himes, Ph.D., Carlisle, Pa.

The explanation usually given in text-books of the depression of a thermometer in the focus of a concave mirror by a piece of ice placed in the focus of an opposite similar mirror, based on the inequality of exchange of heat between the bodies, seems so consistent with the theory of exchanges, that it is generally accepted with little reflection, and it is difficult to understand how any misconception in regard to it can arise. Occasionally, however, upon fuller examination, questions present themselves that seem quite perplexing. In a recent communication to a prominent popular scientific periodical the statement of a leading encyclopœdia, in regard to the experiment, is criticised as an "obvious error," and the theory of exchanges is called in question, and, in a subsequent communication by another, the difficulty is not very satisfactorily disposed of. It may be substantially stated as follows:—All bodies radiate heat, colder bodies only less than warmer ones, at a rate dependent for each one solely upon its temperature. Thus the thermometer before the ice is introduced radiates heat at a rate dependent on its temperature. The introduction of the ice into the focus of the other mirror in no manner affects this radiation, and consequent loss of heat, by the thermometer, whilst the ice on the contrary, not being absolutely cold, radiates heat, which by reflection from the mirrors reaches the thermometer, and should, and does in a measure, replace the heat lost by its radiation; and yet in spite of this increment of heat the thermometer does not rise, but falls. The apparent radiation of cold in this

case, and in all others, if carefully examined, will be found to be only a case of substitution of rays of feebler intensity for some of those *previously received* by a body, whilst the rate of radiation from the body, and consequent loss of heat, remains unchanged; and by considering the part the surrounding objects—the inclosure—play in all such cases the apparent inconsistencies will vanish. When a thermometer has acquired a constant temperature in a room it is receiving and emittting equal amounts of heat. The sum of the radiations from the various points of the inclosure equals the radiation from the thermometer. If a body colder than the inclosure is now introduced near it, as a piece of ice, it will obstruct rays from numerous points, the nearer it is to the thermometer the greater the number, and will send its own feebler rays to the thermometer, whilst it will not in any manner affect the radiation from and consequent loss of heat by the



thermometer, and the thermometer will fall because the amount of heat received will be less than that previously received, whilst that emitted remains the same. The introduction of a mirror, as 1, in the figure so that the thermometer shall be in its focus, does not essentially modify the conditions. The mirror cuts off, it is true, rays from many points of the inclosure, but the thermometer remains unaffected, because rays are substituted from other parts of the inclosure, by reflection from the mirror, which did not reach the thermometer before. Thus rays from *A*, *C*, *B*, are cut off from the thermometer *T*, but are replaced by rays parallel to the axis of the mirror from *A′* and *B′*, whilst that from *C* is replaced by one from *T* normal to the mirror. By the introduction of a second mirror, 2, parallel to the first, these

rays from A' and B' will also be obstructed, but will be replaced by others, as from A'' and B'', that pass through the focus I of the second mirror, and are consequently reflected parallel to its axis, and therefore, by the first mirror to the thermometer. If a body is placed in the focus, I of the second mirror, it will obstruct the rays from A'' and B'' as well, and will send its own rays along the same lines to the mirror, which will reach the thermometer, by reflection from the first mirror; if the body is colder than the inclosnre, as a piece of ice, these rays will be feebler than those from A'' and B'', whilst the thermometer will radiate at the same rate as before, and the thermometer will fall; if it is hotter than the inclosure, for similar reasons, the thermometer will rise. The preceding discussion of an ideal case omits, of course, many factors involved in the actual experiment, as absorption by, and radiation, from the imperfect reflectors, direct radiation from the body to the thermometer, etc. Allusion to these, whilst unnecessary, would have complicated the discussion and would have tended to withdraw attention from the feature of the phenomenon to which it was intended specially to direct it.

A SINGULAR CASE OF CORROSION OF STEEL.

By Prof. Chas. E. Munroe, U. S. N. A.

Through the kindness of Chief Engineer Farmer, my attention has recently been called to the appearance of two cold chisels found in the U. S. S. *Triana* in 1874, and which have since been preserved in the Department of Steam Engineering at the Naval Academy. These chisels were taken from the channelway leading from the jet condenser, and they were located between the foot valve and the air pump. Both chisels were of steel throughout, as was proved by tempering the head. For use, of course, only the points had been tempered. During the time of exposure to the action of the salt water in the channelway the chisels were deeply corroded, but the corrosion was confined entirely to the soft metal, the tempered points not being attacked in the least. The corrosion was deepest at the line of contact between the tempered points and the untempered metal of the haft. The line of immersion, on tempering, is as distinctly marked as if drawn with a shading pen. Since meeting with these chisels, I have

heard of a similar case of corrosion, although the object has been lost. It was a hammer which had been taken from the boiler of a merchant steamer, the tempered faces of which were intact while the soft metal was corroded.

Remembering the heated discussion going on in metallurgical circles on the question "What is Steel?" I shall not attempt to decide whether the change which takes place in the tempering of steel is a chemical or a physical one, but it is evident that this change produces a body which is not so readily acted upon by salt water as untempered steel is. It is also probable that when the untempered and tempered steels are brought in contact in the presence of salt water we have an electro-chemical couple, and that this hastens the destruction of the untempered metal. I beg to suggest that this observation may have a practical bearing upon the construction of steel ships.

Helmholtz's Theory of Double Electric Layers.—G. Lippmann examines Helmholtz's hypothesis, that the difference of potential between two conductors which are in contact implies the presence of a double electric layer, situated at the surface of contact. The hypothesis leads to a parabolic relation of the second degree, between the capillary tension and the difference of potential, and admits of experiments which lead to quantitative results tending to confirm the truth of the hypothesis. From these experiments he infers that the mean value of a molecular interval is $\frac{1}{3500000}$ of a millimetre. This value is $\frac{6}{7}$ as great as that which was found by Sir William Thompson by an entirely different method.—*Comptes Rendus*, Oct. 16, 1882. C.

Solar Induction.—M. Quet examines the hypothesis that the inductive forces, which the sun develops in bodies by his rotation, vary, other things being equal, in the inverse ratio of the squares of the distances. For any body moving in a circular orbit about the sun, in the plane of its equator, the two forces of induction which are applied to it and which are due, the one to its velocity of revolution and the other to the sun's rotation, have a ratio equal to that of the time employed by the sun to make a complete rotation upon its axis and by the revolving body to complete its revolution. He gives a table of the comparative induction upon the several planets and of the immense variations of electric energy in comets, when approaching and receding from peribelion.—*Comptes Rendus*, Oct. 16, 1882. C.

Production of Organic Acids by Electrolysis.—Bartoli and Papasogli have lately published some curious electrolytic experiments. They employed as eleotrodes, in a water voltametre, carbons of coke or of wood purified by chlorine, and noticed that the carbons were attacked, so that the liquid became black; with 1200 Daniells acting for a month without interrnption, the liquid acquires an acid reaction and yields the compounds of the benzo-carbonic series, mellitic acid, with its derivatives, and a black substance composed of carbon, hydrogen and oxygen, slightly soluble in water and insoluble in alcohol and chloroform. The same results were obtained in various acid or alkaline solutions. If graphite is employed the liquid does not become colored. —*Lum. Electrique.* C.

Influence of Electricity on Vegetation.—M. Macagno has experimented near Palermo upon the influence of atmospheric electricity on the growth of grape vines. Sixteen feet were submitted to the action of an electric current, by means of a copper wire inserted by a platinum point in the extremity of a fruit-bearing branch, while another wire connected the branch at its origin with the soil. The experiment lasted from April to September. The wood of the branches which were experimented upon contained less potash and other mineral matters than the rest of the vine, but the leaves had an excess of potash under the form of bitartrate; the grapes collected from the electrized branches furnished more must, contained more glucose and were less acid.—*Les Mondes.* C.

Analysis of Animal and Vegetable Fibres.—Rough analyses of textile fibres may be made by burning or by boiling in nitric acid. Animal fibres emit peculiar odor, burn with difficulty, and leave a spongy coal; vegetables fibres burn readily, without appreciable residue and almost without smell. In nitric acid silk becomes bright yellow; wool deep yellow; cotton, hemp and linen remain white. A better way is first carefully to wash the stuff, then rinse it thoroughly and dry it. The sample is then placed in a solution of caustic soda and boiled until the animal matter is dissolved. The residue is poured upon a filter, which retains the vegetable fibres; these are washed, to remove all traces of soda, dried and weighed. If the sample originally weighed 5 gr. and the residue weighs 1.5 gr., the animal fibre must have been 3.5 gr.; in other words, the proportion of wool in the material is 70 per cent.—*Bull. de la Soc. d'Encour,* Aug., 1882. C.

Air-proof Cement.—C. Pascher finds that the only substance which is really efficacious for rendering cements unalterable by the air, is a cold solution of one part of sulphate of iron in three parts of water. The cement articles are left in the solution for twenty-four hours; at the end of this time they take a greenish-black tint, due to the hydrated protoxide of iron. The absorbed solution is decomposed in the interior of the cement; the weight of the cement is increased ten per cent.; all the pores of the mass are thus stopped by the hydrate, and as this combination is not attacked by the air, the cement itself becomes unalterable. Cement facings may be whitewashed with several coats of the solution. After drying the cement may be covered with a wash of ochre, or by a solution of ten per cent. of sulphate of alumina in three parts of water. For a greenish-white coating, the surface may be first washed with a solution of chrome alum and then with soap-suds. Either of these coats may be painted in distemper. When oil colors are used upon naked cement they easily scale off. This inconvenience may be avoided by washing the cement with soap-suds, letting it dry, and rubbing with a brush or linen cloth until the surface shines. —*Chron. Industr.*, No. 41. C.

Tornadoes in the United States.—M. Faye acknowledges the receipt, from General Hazen, of Finley's report on the character of six hundred tornadoes, which have been observed in the United States during the present century. He finds evidence in the report of a large opening in each tornado, in which all the living force due to the inequalities of velocity in the upper current is stored. The direction of 372 tornadoes was definitely determined; 310 came from the S. W., 38 from the N. W., 18 from S. S. E., 5 from W. N. W., 3 from N. N. E. Hence it appears that the tornadoes are formed almost exclusively in the dangerous semi-circle of a cyclone, and almost always a little in advance. The simultaneous groups of tornadoes are found, almost without exception, in the afternoon, from 3 to 7 o'clock. The hours from 4 to 5 o'clock are those in which the atmosphere, heated to its maximum at about 2 o'clock and consequently expanded, descends by cooling. The upper currents which control the cyclones are due to slight differences of level, like the ocean and river currents. M. Faye recommends that houses should be built facing one of the four cardinal points and provided with barometers, which all the inmates should learn to read and understand.—*Comptes Rendus*, Oct. 16, 1882. C.

Influence of Temperature on Metalloid Spectra.—Kirchhoff and Bunsen have shown that the temperature of the flame in which a metal is reduced to vapor has no influence upon the position of the brilliant lines in its spectrum. When the temperature is raised, fine new lines usually appear, but those which were shown at lower temperatures still remain. This is not the case, however, with metalloids. Plücker has shown that they give two different spectra, according as the tubes are heated by the ordinary spark or by that of the Leyden jar. Van Monckhoven has found, by numerous experiments, that it is possible to produce the spectra which have usually been attributed to high temperature at very low temperatures, and *vice versâ*. By a critical experiment he was able to produce the two spectra superposed, so that, according to Plücker's hypothesis, the gas should have had at the same instant two different temperatures, which is of course inadmissible. He attributes the change of spectra to a special vibratory state of the molecules, directly dependent upon the nature of the electricity employed.—*Comptes Rendus*, xcv, 520. C.

Nature and Propagation of Electricity.—A. Ledieu communicates a note on the rational conception of the nature and propagation of electricity, deduced from the consideration of the potential energy of æthereal matter associated with ponderable matter, and from the mode of production and transmission of the work, which comes from variations of that energy. He calls special attention to the fact that the numerous values which have been obtained, experimentally, for the coefficient of transformation, oscillate about the numerical value of the velocity of light. This circumstance shows an intimate relation between electricity and the cosmic æther. It is, moreover, accompanied by many others, such as the double refraction of glass and of certain liquids under the influence of the induction spark; the rotation of the light reflected upon a magnet; the action of light upon the electric conductibility of selenium in the photophone. M. Ledieu considers that the hydrodynamic imitations of electric and magnetic effects, by Bjerknes and Decharme, furnish only false analogies, and he thinks it indispensable, while abandoning the notion of electric flow, neither to assume the idea of waves nor of molecular shocks, but simply to consider the action of central forces.—*Comptes Rendus*, Oct. 16, 1882. C.

Signals to Prevent Collisions at Sea.—Captain Littrow, of the Austrian marine, proposes to add to the green lantern upon the right and red upon the left of the vessel, two similar lanterns upon the prow. In this way, when two ships are in a straight line the lights of the stern are hidden by those of the prow; if, then, one of the boats turns to the right, it displays the red lights of its left, and the other ship, turning in the opposite direction, will show the green lights of its right. If one of the ships should see suddenly before it two red or green lights its path would be perpendicular to that of the vessel which it is approaching, and it should stop immediately.—*Chron. Industr.*, No. 41. C.

Origin of Storms.—Spring attributes the appearance of a thunder-storm to a sudden condensation of atmospheric vapor, not into a mist but into hail. The source of the electricity is the rupture of the adherence of the air to the particles of hail; the electric influence then carries the electricity, which was accumulated upon each particle of ice, to the particles which form the limit of the frozen region. Abbé Moigno fears that this theory rests on a vicious circle, for the condensation of water, under the form of hail or of rain, can only take place by reason of an electric discharge. All the secret of thunder-storms is to be found in a *nimbus* encountered by a very cold, very dry and highly electrified *cirrus*.—*Les Mondes*, iii, 254. C.

The Sense of Direction in Animals.—The remarkable faculty which cats, dogs, pigeons, and other animals possess, of returning in a straight line to a point of departure, has awakened much curiosity on the part of naturalists. Some refer it to instinct, some to intelligence similar to that of man, some to an internal mechanism which makes the animals simple automata; but none of these attempted explanations do anything towards solving the mystery. Wallace supposed that when an animal is carried to a great distance in a basket, its fright makes it very attentive to the different odors which it encounters upon the way, and that the return of these odors, in inverse order, furnishes the needful guide. Toussenel supposes that birds recognize the north as the cold quarter, the south as the warm, the east (in France) as the dry, and the west as the moist. Viguier, in the *Revue Philosophique*, publishes an original memoir upon the sense of orientation and its organs, in which he attributes the faculty to a perception of magnetic currents.—*Chron. Industr.*, Nov. 2, 1882. C.

New Method of Cutting Glass.—M. Fahdt, of Dresden, uses metallic wires heated to redness by electricity, for cutting glass. When the circuit is closed the wire communicates its heat to the glass, which cracks under the influence of a sudden cooling by contact with a moist body. To remove the inequalities of the section, it is exposed to a flame by turning so that the flame will reach all the points. The object is then placed in an oven, in order to prevent the parts which have been heated by the flame from cooling too suddenly. —*Chron. Industr.*, No. 37. C.

Combustion of Carbon at High Temperatures.—It has generally been believed that high temperatures favor the formation of carbonic acid, while low temperatures favor the formation of carbonic oxide. Prof. Ledebur has burnt definite weights of charcoal at different temperatures with definite volumes of air, measuring, in each instance, the quantities of carbonic acid and of carbonic oxide which were given off. On gradually increasing the temperature from 350° to 1100° (662° to 2012°F.) he observed an increasing proportion of carbonic oxide and a decreasing proportion of carbonic acid. At the highest temperature the gas was almost exclusively carbonic oxide. These results are contrary to the theories which have been generally admitted by metallurgists.—*Chron. Industr.*, No. 40. C.

Limits of Electrolysis.—The labors of Joule and Favre have established some definite relations between electro-motive forces and the heats of combination in metals. The application of these laws to the electrolysis of salts is often very obscure, especially where secondary actions are produced and where it is desired to know the exact sum of all the energies which really concur in the electrolytic phenomenon. Berthelot has accordingly studied nascent electrolysis, before the composition of the saline solutions has been complicated by the progress of decomposition. He finds that the limit of the efficacious electro-motive forces is uncertain when there is polarization: in order to allow for the polarization it would be necessary to know the real nature of the compounds and their proper heat of formation. Independently of this complication, he finds in electrolysis, as in thermo-chemistry and in a multitude of natural phenomena, the mechanical principle of least action.—*Ann. de Chim. et de Phys.*, xxvii, No. 89. C.

Watch Glasses.—The watch glasses which are now used are moulded by a process which was invented, in 1791, by Pierre Royer, a Parisian manufacturer. C. Launier gives an interesting description of one of the large factories and of the different processes of manufacture. Two and a half million watches are now made annually, and more than seventy millions have been sold within the last half century. On account of the large consumption, and the large stocks which every watchmaker requires to keep on hand, the annual product of watch glasses cannot be less than a hundred million.—*La Nature*, Oct. 21, 1882. C.

Irrigation in Algiers.—M. Jus has addressed to the French Société d'Encouragement some notices, charts, and pictures referring to the Algerian oases and the animals which live in the artesian wells. He gives interesting statistics respecting the settlements, the dwellings, the palm and fruit trees, the value of the annual products, the increase and results of irrigation, which have raised the annual production from 1,654,000 francs in 1856 to 5,549,018 francs in 1880. The improvements have saved from ruin many oases which were upon the point of being relinquished, and have extended the blessing of peace over a region which was always at war before the French occupation; moreover, they have largely increased the material well-being of the native tribes.—*Bull. de la Soc. d'Encour.*, Aug., 1882. C.

Injurious Modes of Lubrication.—Schoudorf recounts the examination of the large cylinder in a Woolf engine, employed in the mines of Sarrebruck. On opening the cylinder there was found upon the piston a brown, wax-like mass, weighing more than 150 kilogrammes (330·7 lbs.). It contained 60 per cent. oxide of iron, 26·77 per cent. of organic matters soluble in alcohol, 5·7 per cent. of insoluble organic matter, the residue being composed of water with a little silicic acid. The cylinder had been in use for about a year, during which time 192 kilogrammes of suet had been employed for lubrication. The decomposition of the suet by steam into glycerine and fatty acids led to the formation of a soap of protoxide of iron. The oxidation of the iron, which is limited chiefly to the interior surface of the cylinder, gradually produces an enlargement of the diameter. The evil may be obviated by using as a lubricant mineral oil of good quality, which boils only at a very high temperature.—*Chron. Industr.*, Oct. 12, 1882. C.

A New Genesis.—On a beautiful summer's night, August 22, 1794, Jerome and Lefrançais de Lalande noticed a star in Aquarius, which they estimated of the 7½ magnitude. Six years later they thought it of the 8 magnitude. In appearance it resembles a star, which is not exactly in the focus of the telescope. Herschel had observed it in September, 1782, and recorded it as an admirable planetary nebula, very brilliant, small, and elliptical. Lord Rosse and Lassell perceived that it was surrounded by a ring, which gives it somewhat the appearance of Saturn. The spectroscopic observations of Huggins indicate that it is a gaseous mass, in which nitrogen and hydrogen predominate. Most of the other planetary and annular nebulæ give similar results. In 1871 and 1872, Brunnow, the Irish astronomer royal, measured its parallax, and concluded that its distance is more than 404,000 times as great as that of the sun, and its diameter is probably greater than that of the entire solar system. This would make its volume more than 338,896,800,000,000,000 times as great as that of the earth. We have thus before our eyes a new system, which is probably undergoing the process of condensation, through which our sun and its attendant planets passed hundreds of millions of years ago.—*L'Astronomie*, Oct., 1882. C.

Franklin Institute.

HALL OF THE INSTITUTE, March 21, 1883.

The stated meeting of the Institute was held at the usual hour, with the President, Wm. P. Tatham, in the chair.

Present, 220 members and 30 visitors.

The minutes of the last meeting were read and approved.

The Actuary submitted the minutes of the Board of Managers, and reported that at the meeting held March 14, 1883, 16 persons had been elected to membership.

The Secretary, from the Committee on Science and the Arts, reported, by instruction, that the Committee had recommended the award of the Scott Legacy Medal and Premium to Hugo Bilgram, of Philadelphia, for his improvement in Gearing for Metal Planers, and to Thomas Shaw, of Philadelphia, for his improvement in Friction Buffers. He

also reported that the above recommendations had been duly advertised for three months, and that no objections had been offered thereto.

The recommendations were thereupon taken up separately and approved without dissenting vote, and the Secretary was instructed to notify the Committee on Minor Trusts of the Board of City Trusts, of the action of the Institute.

The Special Committee on the Prevention of Fires in Theatres reported progress, and was continued.

Mr. William B. Le Van then read a paper entitled "Sixty Miles an Hour on Present Road-beds." The speaker claimed that this average speed could readily be maintained upon existing road-beds by introducing a suitable cut-off valve upon the locomotives. He exhibited a series of diagrams taken from well-known locomotives, showing their relative economy. Among them were diagrams from a locomotive in use on the Central Pacific Railway, and provided with a cut-off valve, which showed a very close approximation to the theoretical diagram (about 90 per cent.), and showing a mean effective pressure in the cylinder of 92 pounds to the square inch; whereas, in the diagrams taken from our best fast passenger locomotives, the average mean pressure in the cylinder only averaged 44 pounds, and the efficiency of the engines averaged but 60 per cent. The speaker also advocated the use of higher pressures (up to 210 pounds) as a measure of economy. The paper has been referred for publication.

Mr. William Morris Davis followed with a paper on "Charcoal as applied to the Deposition of Gold from Chlorine Solutions, and its perfect Separation from Copper and other Impurities." The paper is published in this issue of the JOURNAL.

Mr. Otto C. Wolf, by request, described a large sized model representing the valve mechanism of William F. Goodwin's High Speed Engine. The peculiarity of this engine consists in having four distinct valves—two steam and two exhaust valves—circular in form, similar to those in use on the Corliss engine, but differing in respect to location, two being placed in the front head and two in the back head of the cylinder, thereby reducing the clearance space to a minimum. The clearance is further reduced by providing projections or lugs on both faces of the piston, which fill the inlet and outlet ports when the piston is at the extreme ends of its stroke, thereby reducing the clearance in practice to 1·8 per cent. of piston displacement.

Mr. Wolf here took exception to Mr. Le Van's statement that the

placing of an independent cut-off valve upon locomotive engines would overcome the wire-drawing that nearly all the indicator cards showed at high speeds. Mr. Wolf made the point that the steam passages were not properly proportioned, and even if the cut-off gear would allow entire opening of the ports, the passages themselves would wire-draw the entering steam. An instance was cited where the steam would require to have a velocity of over 20,000 feet per minute to follow the piston at the high speed of the engine. If the question of port area were properly considered and proportioned to the maximum speed desired of the engine, future locomotive indicator cards would not be subject to the criticism that they are at present. By such an arrangement of valves as in Mr. Goodwin's model, this could be done without increasing the clearance space. Mr. Rufus Hill had demonstrated upon the engines of the Camden and Atlantic Railroad the importance of this question.

Mr. Le Van asked why the exhaust valves were not placed on a level with the bottom of the cylinder instead of being located some 4 inches above the bottom, thereby incurring the risk in locomotive practice of damming the water in the cylinder instead of giving free access of the same by gravity to the exhaust port, as is ordinarily done in the Corliss, Wheelock, Buckeye, and other engines.

Mr. Goodwin replied that were he to place the exhaust valves as suggested by Mr. Le Van, he would be unable to have the projections or lugs on the piston to assist in reducing the clearance as above stated.

Mr. Robert Grimshaw, by request, exhibited on the screen several views, showing the action of the valve movement of the Shaw Locomotive, explaining the questions of the lead and lap of both steam and exhaust sides of the valve.

The Secretary's report included a description of the following mechanical novelties:

The Hall Type Writer, an illustrated description of which will appear in the JOURNAL; Spicer's Fire Escape, consisting of two series of passage or escape-ways, one being within the building, and the other exterior thereto. The inner passage-ways are enclosed by masonry, and the outer ones by metallic sheathing. Each floor of the building is provided with one of these inner passage-ways, which is furnished with an inwardly opening door, kept closed by a spring or weight. The inner passage-ways communicate with the outer ones, and the latter are provided with ladders or staircases, by means of